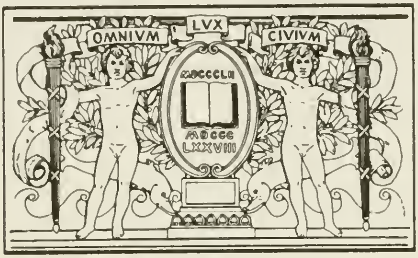
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SPACE TELESCOPE COST, SCHEDULE, AND PERFORMANCE

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-EIGHTH CONGRESS

FIRST SESSION

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CONTENTS

WITNESSES

SPACE TELESCOPE COST, SCHEDULE AND PERFORMANCE

TUESDAY, JUNE 14, 1983.

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

The subcommittee met, pursuant to call, at 2 p.m., in room 2325, Rayburn House Office Building, Hon. Harold Volkmer (chairman of the subcommittee) presiding.

Mr. VOLKMER. The subcommittee will come to order.

Today the Subcommittee on Space Science and Applications begins 2 days of hearings on the technical, cost, and schedule problems which have occurred with the space telescope program.

The space telescope program represents NASA's highest priority science program and represents a very significant, if not revolutionary, addition to our ability to study the universe. The subcommittee continues to exhibit strong support for the successful completion of this program but is very concerned with the cost growth and schedule slips which have occurred.

We want to review not only the events that led to this large cost growth and the schedule delays but to also look at the program changes which have been made to hopefully provide better performance in the future.

The tragedy of this cost growth is that the additional resources needed for the space telescope will severely impact and delay other space science activities. The schedule delay means we will have missed the opportunity to study Halley's comet during its voyage around the Sun, which will come closest to the Earth in February 1986.

Our witnesses today are Dr. William R. Lucas, Director, Marshall Space Flight Center; Dr. Noel W. Hinners, Director, Goddard Space Flight Center; and Dr. Riccardo Giacconi, Director, Space Telescope Science Institute.

Dr. Lucas, I would like to welcome you to the subcommittee. After I ask the ranking minority member, Mr. Lujan, if he has any statement, you may proceed with your testimony. Your full statement will be made a part of the record. You may summarize, if you wish.

At this time, I will recognize the gentleman from New Mexico for a statement, if he wishes to make one.

Mr. LUJAN. Thank you, Mr. Chairman.

I am certain that all three of our witnesses today share the enthusiasm for the scientific uses of the space telescope. Since we have all been excited with previous programs and planetary exploration, the ability of the space telescope to better study our own solar system is particularly thrilling.

Add to this the ability to not only better understand our galaxy, but to see galaxies outside our own, and one can understand why scientists and others are all chomping at the bit to see the telescope launched.

Because of this, our disappointment with the delays and cost overruns is very acute. At this point it doesn't look like we can make these delays and cost overruns go away, but we certainly want to make sure there will not be any additional problems.

I believe that as members of this House Committee on Science and Technology, we are all aware that this program, which is expected to allow quantum leaps in the field of astronomy, physics and such, is a technical challenge.

Likewise, we are familiar with the unexpected problems that can arise with developing instruments at the forefront of our technical and engineering capabilities. So, we recognize that delays and, consequently, cost overruns can be expected.

In the hearings today and Thursday we will be concerned that the necessary changes have been made to insure the success of the program. I understand that many of the components of the space telescope are of very high quality, possibly even better than the demanding design criteria. This encouraging fact will continue to make all of us most anxious to see this space telescope launched.

We are also concerned about how these cost overruns affect other programs. These delays and cost overruns have meant that other space science programs will be delayed, which is more than likely to result in cost overruns for these programs as well.

While we are all concerned about the national deficit and keeping the Federal budget as trim as possible, it is particularly painful to have exciting programs like space science troubled with cost overruns. Hopefully careful planning can minimize these negatives.

There are lessons to be learned from our experience with the space telescope program. Hopefully we can use these hearings as an opportunity to insure that future programs are on schedule and within budget.

Mr. Chairman, I look forward to talking with our witnesses this afternoon on how we will be able to insure the success of the space telescope program, which will give us the ability to see so much farther back in the history of the universe.

Thank you, Mr. Chairman.

Mr. Volkmer. Dr. Lucas, you may proceed.

STATEMENT OF DR. WILLIAM R. LUCAS, DIRECTOR, GEORGE C. MARSHALL SPACE FLIGHT CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY JAMES B. ODOM, SPACE TELESCOPE PROJECT MANAGER; JEAN R. OLIVIER, CHIEF ENGINEER, SPACE TELESCOPE; AND WILLIAM HUDSON SNEED, ASSISTANT DIRECTOR FOR POLICY AND REVIEW

Dr. LUCAS. Thank you, Mr. Chairman.

I appreciate the opportunity to appear before your subcommittee today to discuss the status of the space telescope. I would like to present some of my colleagues who are with me today.

Mr. Bill Sneed, to my right, is the Assistant Director for policy and review at the center and has spent about 50 percent of his time in the last several months on the space telescope. I also have with me the new manager of the space telescope at the Marshall Center, Mr. Jim Odom, and the chief engineer of the space telescope project, Mr. Jean Olivier.

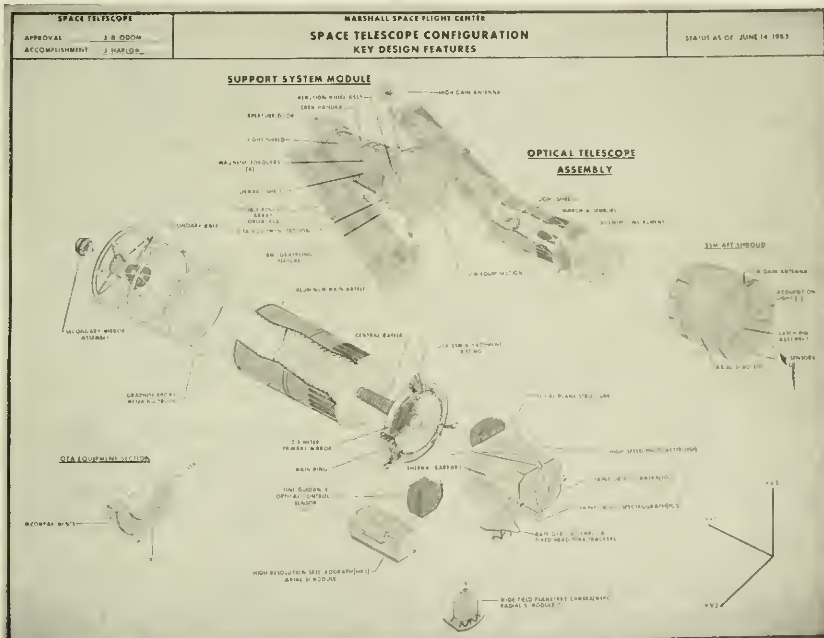

FIGURE 1

The space telescope consists of three major systems. I know you have seen these many times before, but as a reminder I have placed on the screen a slide (figure 1) showing the various elements of the space telescope, the optical telescope assembly, the support system module, and the five modular science instruments. The solar arrays, a separable unit of the space telescope, are being supplied by the European Space Agency.

With your permission, I will summarize my prepared statement, giving attention only to those elements which are the responsibility of the Marshall Space Flight Center.

We are responsible for the overall management of the space telescope; for the direct management of the optical telescope assembly, which is being developed by the Perkin-Elmer Corp.; and the support-systems module, being developed by the Lockheed Missiles and Space Co. In addition, we are responsible for the systems engineering and integration activity, done with Marshall people and with support primarily from the Lockheed Corp.

The space telescope key requirements were developed during the mid-1970's through an intensive definition period by NASA, in conjunction with the science community. These key requirements are consistent with the fundamental objective of taking full advantage of the space environment for optical astronomy. They are responsive to the performance specifications established by the science community.

The requirements have been submitted in detail in my prepared statement and I will only mention them now as the base of our discussion.

First of all, the space telescope is required to have a long life, 15 years or more, in orbit. It is designed to permit exchange of instruments in orbit. It is designed to observe faint objects 50 times more fainter than can be observed from ground-based telescopes. It must have an image resolution of one-tenth arc second and an image stability of one-tenth of that very small angle. It must be able to perform both on the dark and the bright sides of each orbit.

These stringent requirements for the space telescope resulted in some major engineering challenges in many areas of technology and advancements in the state of the art in others, for example, polishing of the mirror, pointing system accuracy, torque-free mechanisms that were required, contamination control and thermal control to keep a part of the telescope's focal plane structure at a constant temperature in orbit; by that I mean 70° plus or minus two-tenths of 1° Fahrenheit.

I am pleased to report that many of these component specifications derived from these requirements have already been demonstrated by tests. We have no reason to believe, at this time, that the space telescope will not satisfy all the basic defined requirements.

I will summarize how these requirements have driven the design of the space telescope and have resulted in some of the problems that we have encountered, although I would hasten to add that the achievements that have been made have been very significant indeed.

The optical telescope assembly—and you may refer again to figure 1—is the heart of the space telescope observatory. It provides the fundamental optical system, the target acquisition at precise attitude control, and it provides for the mounting of the instruments.

It consists of a 96-inch mirror, the primary mirror; a 12-inch secondary mirror; and a metering truss, which maintains alinement and precise distance between the mirrors. The distance between those two mirrors is about 24 feet. The truss is required to maintain that distance to within about 1/10,000 of an inch. That is equivalent to about one-tenth the thickness of a sheet of paper. It also contains a baffle system to minimize the stray light, a focal plane structure to which the science instruments and the fine guidance sensors are mounted, and a main ring, which serves as the primary mount for the mirror. The assembly includes the fine guidance sensors with their associated electronics, which are mounted in the instrument section.

The optical telescope assembly has clearly been our most troublesome part of the project. The early assessments were that the primary mirror polishing to meet the surface criteria would represent the most difficult task. Accordingly, major emphasis was placed at Perkin-Elmer on this task at the start of the program.

It turns out that the most notable technical achievement to date has been the fabrication and polishing and coating of this 96-inch mirror. To fabricate a mirror of this size and quality required coating and polishing facilities and techniques that heretofore had been unavailable to the optical industry.

Then problems were associated with the mounting of the through-the-glass hardware, the bonding of attaching mechanisms to the mirror and all other things that would cause the slightest amount of distortion of the mirrored surface. This was quite an undertaking and did require significantly more time during the fall of 1982 than we originally planned. However, the assembly has now been successfully completed and we have a flight-mounted mirror of unprecedented quality, exceeding even the rigorous specifications established for the project. This is also true for the secondary mirror assembly.

There have been recent discussions about the contamination of the primary mirror. Visible particulate contamination—that is, very fine dust—does exist on the primary mirror despite the very rigorous control that we have applied to it. Recent determinations have indicated that two-tenths of 1 percent of the mirror surface contains particulate matter. This is well within the 1-percent surface coverage criteria that had been established for time of launch.

A substantial period of time remains before we launch, and due to the projection of future accumulations we plan to clean the mirror as a safeguard against any performance degradation resulting from particulates. We will develop a cleaning method and will conduct that cleaning at the lastest possible time in the schedule.

Molecular contamination is a different matter. Insofar as we know, we have no molecular contamination or thin film over the mirror at this time. If we did, it would be of very significant consequence. We are presently investigating methods for testing for molecular contamination on the mirror, and we will undertake testing and cleaning later, if it is indicated to be necessary.

As a precaution against future molecular contamination or any contamination resulting from the telescope structure, we will vacuum bake those parts of the structure that could contribute thin films or molecular contamination.

The very precise alinement requirements that must be maintained for many hours to collect the light from the faintest stars dictated utilization of materials on several elements that would be essentially unchanged by extreme temperature variations. These temperature variations result from traversing from the light side to the dark side of the orbit, and also from varying orientations of the spacecraft to the Sun.

We eventually solved some of these problems by changing from the original titanium structure to a graphite epoxy structure in some of the critical areas of the OTA. Even with that it was necessary to apply heaters rather extensively on the system to meet the thermal requirements, but we now believe that we have satisfied those requirements.

The fine guidance sensor is a key element of the space telescope pointing and control system. It has been and continues to be one of the most troublesome items in the OTA. The fine guidance sensor enables the pointing control system to lock onto the desired object in space by way of two known guide stars and to maintain that position with the extremely high accuracy of about 100th of an arc second for periods of up to 24 hours.

There have been development problems. The most significant one has been associated with the Koesters' prisms that generate the data needed to provide the pointing precision of the space telescope. Due to imperfections in some of these prisms, the initial characteristics of the interferometer that is made from these prisms were poor and not repeatable. It has been learned that with very careful selection and evaluation of the prisms on hand that satisfactory prisms, at least a small number, are available and, in fact, can be generated. So, this problem seems to have become one of getting adequate quantities manufactured.

In view of the problems that we have encountered on the fine guidance sensor, it was decided to initiate a total systems testing of the fine guidance sensor as soon as possible. To accomplish this, the first flight unit has been designated as an engineering model. The engineering model will allow testing in the fall of this year, prior to the completion of the flight units.

In addition, because of the lingering concerns about the fine guidance sensor, we initiated, a few months ago, a backup design at the Applied Physics Laboratory at Johns Hopkins University with Professor Fasti as the principal investigator. He is also being assisted by Professor Westphal and others. This is not a total backup system, but a backup of that part of the system now satisfied by the Koesters' prism interferometers. It constitutes only about 5 percent of the total fine guidance sensor. I believe that the actions that we are taking now are prudent to assure the functioning of the fine guidance sensor. We will demonstrate this in the test to be conducted by this fall.

Development of latches to hold the science instruments and the fine guidance sensor was another problem that we encountered. There are 27 of these latches, each consisting of two different pieces. They are required to allow the replacement of instruments on orbit. They must maintain alinement within a few thousandths of an inch. They also serve the additional function of insulating the instrument from heat transfer through the structure. Of course, development of these very exacting requirements was a difficult task, but it appears to have been solved. The first group of latches has now completed the qualification testing, with a new coating on the mating surfaces, and the coating of flight latches is underway.

Qualification testing of the second and final group of latches will be done in August of this year.

Another problem that we encountered on the space telescope assembly was the availability of adequate special test equipment to accomplish the alinement and to maintain the tolerances necessary. We had to add some special test equipment to the program. This has driven a portion of the need for additional funding.

The primary challenge and schedule risk remaining to the optical telescope assembly project are the successful completion of the fine guidance sensor and its associated electronics, and the successful assembly, alinement and verification of the OTA. We expect to have the risk associated with the fine guidance sensor clearly identified upon the completion of the test that I mentioned previously.

The support systems module, which has already been referred to on the chart, provides the basic spacecraft services, including the pointing control, the electrical power, the data management, and thermal control. In addition, it provides structural accommodations and the light shield for the OTA and the science instruments.

The support systems module has made generally satisfactory progress. A few problems have been mentioned in the prepared statement, and I will not repeat them here. However, I would call your attention to the most significant current problem on the support systems module. That is associated with the data management system, which encompasses the flight software and the data management unit. The flight software has exceeded the memory utilization specification of the data management system flight computer. That specification was established to assure that 20 percent of the active memory capability would be available at launch time to take care of unanticipated problems that might be encountered after reaching orbit. Studies are underway, and we believe that we will be able to reestablish this 20 percent active memory capability.

The primary challenge and schedule risks remaining for the support systems module effort are the completion and integration of the flight systems, the support equipment, and also the verification of assembly testing and orbital checkout of the entire telescope. Planning for all of these activities is proceeding satisfactorily.

Systems engineering is a function of very great importance to the program, and particularly at the point in the program that we have reached. We did restrict, for cost considerations, the systems engineering and integration activity in recent months, although I don't believe that effort has affected the program negatively. We are now increasing that as we come to the very important time of bringing all the various components together into the final system and for the checkout and verification of the systems.

The extreme complexity that I have just alluded to and the very exacting requirements, coupled with some of the inherent problems associated with the early project decisions, have made it extremely difficult to maintain schedules or to accurately predict cost requirements. Consequently, it has been necessary for us to defer work to later years to stay within annual budgets. While the deferral of the work provided the solution to near-term problems, it could now be judged to have introduced too much schedule risk into a project of such complexity.

The difficulty in accurately predicting the cost requirements also resulted in our having had inadequate funds or reserves for coping with the unanticipated technical and programmatic problems which have further impacted our development schedules. Our previous baseline required delivery of the OTA to Lockheed from Perkin-Elmer in December 1983, with a launch of the space telescope in the first half of 1985. It now appears that the OTA will be delivered to Lockheed in November 1984, with a launch of the space telescope in mid-1986.

The resolution of the development problems, the additional testing that we have introduced, and spares that have been added in the project rephasing to reduce the risk, the increased systems engineering and integration effort introduced to facilitate projectwide integration, and the extended development schedule have resulted in a sizeable increase in our development funding requirement. For example, in fiscal year 1983 we had authorized and appropriated $137.5 million for the space telescope development. It now appears that we will need approximately $45 million more or approximately $183 million. We now estimate that about $195 million will be required in fiscal year 1984, or an increase of about $75 million over that contained in NASA's fiscal year 1984 budget request.

The new schedules have been provided to all the participating organizations, and revised schedules and revised cost estimates through completion are being prepared and will be available later this summer. Our current schedule problems and cost problems began to significantly manifest themselves in the fall of 1982. The optical telescope assembly was falling behind at an increasing rate, and it was becoming more evident that the schedule could not be recovered and that additional manpower would be required to complete all the remaining activities.

In September 1982, I initiated a comprehensive review of the OTA at Perkin-Elmer with a number of the top management and technical directors from my center. This assessment was directed to a lower level of activity than usually required at aerospace contractors, and the assessment confirmed significant design and manufacturing problems with the fine guidance sensor, with the latches, and with special test equipment and the resultant overall schedule deterioration in the final assembly.

In December 1982, I initiated a similar programmatic review of the support systems module at Lockheed to ascertain the technical status and to validate the cost and schedules being reported to the Marshall Center. Since that time, there have been other NASA headquarters and congressional review teams assessing the space telescope project.

The cost and schedule concerns and the need for major improvements at Perkin-Elmer that we reported to this subcommittee in February 1983 have now been confirmed. We reported, at that time, that certain corrective actions had been initiated. Subsequently, we have identified other corrective actions in order to reduce the technical and schedule risks associated with the project. One of the things, for example, that we have done is to advance some of the testing at Lockheed in order to increase our margin for completing that testing. We have also made significant management changes that I would like to refer to at this time.

At the Marshall Space Flight Center, we have appointed a new manager for the space telescope office, whom I introduced to you earlier in the presentation, Mr. Jim Odom. This made available to the space telescope, during this critical assembly and test phase, a highly succesful hardware manager from the shuttle program. Jim just came from the very successful external tank project of the shuttle program. A highly qualified former laboratory director was also appointed as deputy to Jim Odom and he will have full responsibility for discharging all the systems engineering activities at Marshall and across the program. He is supported with a newly formed systems engineering project office and a somewhat beefed-up systems engineering organization at the Marshall Center, as well as being supported by a newly formed, dedicated systems engineering organization at the Lockheed Co.

We believe that these system engineering changes will enhance our analytical integration, verification and operational planning for all elements of the space telescope project and will increase involvement of the science community in these important activities. There have been formed within our space telescope office two subordinate offices, the optical telescope assembly project office and the support systems module project office, each having full authority for the management of their respective system. This will allow the space telescope project manager to concentrate his full attention on directing the overall project.

Because of the concerns that we had with respect to the OTA, the newly appointed OTA manager and his entire staff have been located on site at the Perkin-Elmer facility to obtain visibility to a level of penetration on a daily basis not usually necessary for the direction of contractor effort.

The Perkin-Elmer company has also made important management changes to strengthen the management and programmatic discipline at that company. They have appointed a new, experienced manager of the project, and he is supported by two deputy program managers, one dealing with the OTA assembly and one specifically working on the fine guidance sensor and the optical control system. In addition, he has an assistant director for engineering to coordinate the overall day-to-day engineering activity. Other improvements have been made, which I am sure Perkin-Elmer will mention to you, in great detail, on Thursday. The executive vice president of Perkin-Elmer became the acting head of the optical group under which the telescope project is assigned. In this capacity, he has also made several changes to strengthen his management structure. We expect that a new executive over the optical telescope group will be appointed momentarily.

The only change at Lockheed is that the systems engineering activity that is done across the program and to support the Marshall Space Flight Center has been pulled from under the support systems module and will report directly to the Lockheed vice president for NASA programs.

In conclusion, while the space telescope has presented considerable technical challenge, most of the challenges have been met successfully. Very substantial progress has been made on all of them, and we believe that we have developed a firm understanding of the job yet to be done.

Our management has been strengthened across the entire project. While other challenges may be encountered, we believe that we are in a position to meet them. We are in the process, as I have mentioned, of developing revised schedules and cost which will embody the necessary reserves to accommodate the normal development problems that are to be expected. I am confident that the project will be successfully completed and that all the key science objectives will be met.

That completes my oral statement. I will be pleased to receive any questions.

[The prepared statement, plus answers to questions asked of Dr. Lucas follows:]

STATEMENT

of

DR. WILLIAM R. LUCAS
DIRECTOR, MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

for the

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS
COMMITTEE ON SCIENCE AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

Mr. Chairman and Members of the Subcommittee:

I am pleased to present the status of the Space Telescope Project with special emphasis on elements for which the Marshall Space Flight Center has primary responsibility; technical and management problems which are the major contributors to our current cost and schedule problems; my assessment of current project status; major challenges to be faced in the future: and management changes which have been made. Since I will be followed by Dr. Noel Hinners, who will testify on science instruments and ground operations and by Dr. Riccardo Giacconi on the Science Institute, I will touch only briefly on these elements. Although the Subcommittee is familiar with the Space Telescope Project, I will briefly review the elements of the project, the responsibilities of the various organizations involved, and the key requirements of the project to provide a context for the discussion.

PROJECT ELEMENTS

The Space Telescope consists of three major systems, the Optical Telescope Assembly, the Support Systems Module, and five modular science instruments which are the Wide Field Planetary Camera, the Faint Object Camera, the High Speed Photometer, the High Resolution Spectrograph, and the Faint Object Spectrograph. These elements are identified on Figure 1. The Solar Arrays constitute a separable element of the Support Systems Module. In addition to these hardware elements, the Project also includes the Mission Operations Ground System, the Science Institute and Systems Engineering and Integration.

MANAGEMENT RESPONSIBILITIES

The Marshall Space Flight Center (MSFC) has the overall project management responsibility for the Space Telescope. MSFC also has direct management responsibility for the Optical Telescope Assembly being developed by Perkin-Elmer Corporation, the Support Systems Module being developed by Lockheed Missiles and Space Company, and the Systems Engineering and Integration activities with support from Lockheed.

The Goddard Space Flight Center (GSFC) has responsibility for the management of the Science Instruments development, the Science Institute located at Johns Hopkins University, and the Mission Operations Ground System.

The European Space Agency is responsible for the development of the Solar Arrays, with the associated drive mechanisms, and the Faint Object Camera. In addition, the European Space Agency is participating in the staffing of the Space Telescope Science Institute.

SPACE TELESCOPE REQUIREMENTS

To provide a basis for the remainder of this statement, it is appropriate to review the requirements established for the project and the associated technical challenges.

The Space Telescope key requirements (Appendix A) were developed during the mid-1970's through an intensive definition period by NASA in conjunction with the science community. These key requirements are consistent with the fundamental objective of taking full advantage of the space environment for optical astronomy and are responsive to the performance specifications established by the science community. These requirements are summarized as follows:

> The Space Telescope is required to be a versatile, long-lifetime observatory with up to 15 years orbital operations. It is to accommodate at least four science instruments, such as cameras and spectrographs and permit exchange of these instruments in orbit, either for repair or in exchange for next generation instruments. The overall Space Telescope system is required to work efficiently in the entire visible spectrum from blue to red and much beyond into the invisible ultraviolet and infrared wavelengths that are inaccessible to ground observatories.
>
> The Space Telescope is required to measure objects appreciably fainter than those accessible from the ground. In practical terms, the requirement is for observation of objects fifty times fainter and seven times farther into space than possible with the best ground-based telescopes, increasing the volume of space available for observation by a factor of 350.
>
> The sharpness and resolution of images is one of the most important characteristics. This determines how well extended sources such as galaxies or nebulae can be observed. The requirement calls for a resolution of 0.1 arc second and an image stability of one-tenth of that very small angle. One can visualize such a small angle by comparing it with the diameter of a dime held up in Boston as seen from Washington, D. C.
>
> To take full advantage of the telescope capability, observations will be performed on both the dark and bright side of each orbit. During planetary observations, it must be capable of tracking planets and comets at their highest angular speed, and rotating features on such moving objects.

PROJECT STATUS

The stringent requirements for the Space Telescope resulted in major engineering challenges in many areas of technology and advancements in the state-of-the-art in others; for instance, mirror surface precision, pointing system accuracy, torque-free mechanisms, contamination control, thermal control to keep the Telescope focal plane structure at a constant temperature of 70 $\pm$ 0.2^{o} Fahrenheit in space, and the measurement of single photons from a distant star. I am pleased to report that many of the component specifications derived from these requirements have already been demonstrated by test, and we have no reason to believe at this time that the Space Telescope will not satisfy all its basic requirements. I will summarize how the requirements drove the design of the Space Telescope, the problems encountered, and the current status of each element of the project. Although substantial progress has been made, it has not been without significant cost and schedule impacts as was identified in our February 1983 testimony to the Subcommittee.

Optical Telescope Assembly

The Optical Telescope Assembly is the heart of the Space Telescope observatory. It provides the fundamental optical system, target acquisition and precise attitude control, and for science instrument mounting. It consists of a 96-inch primary mirror, a 12-inch secondary mirror, a metering truss which maintains alignment and precise distance between the mirrors, a baffle system to minimize stray light, a focal plane structure to which the science instruments and Fine Guidance Sensors are mounted, and a main ring which serves as the primary mirror mount. The Optical Telescope Assembly also includes three Fine Guidance Sensors with their associated electronics mounted in an equipment section.

The design, development and fabrication of the Optical Telescope Assembly has clearly been our most troublesome problem. Early assessments indicated that fabricating the primary mirror to meet the stringent surface criteria would represent the most difficult task, and major emphasis was placed at Perkin-Elmer on this task at the start of the program. In addition, a back-up primary mirror was initiated at Eastman-Kodak early in the program using a different polishing technique from that to be used by Perkin-Elmer to provide assurance of developing a flight quality mirror. The back-up mirror polishing was completed, but the mirror was not coated because of the satisfactory progress on the Perkin-Elmer mirror, and the back-up mirror is in storage now.

The primary and secondary mirrors have now been fabricated by Perkin-Elmer and are better than our design specifications. In fact, the singularly most notable technical achievement to date is the fabrication, polishing and coating of the 96-inch primary mirror. To fabricate a mirror of this size and quality required coating and polishing facilities and techniques heretofore unavailable to the optical industry. The mounting of the through-the-glass hardware, the bonding of attaching mechanisms, and all other primary mirror assembly operations which could distort the mirror proved to be a substantial technical undertaking, and required significantly more time during the fall of 1982 than planned originally. These assembly processes have now been successfully completed, and we have a flight mounted primary mirror of unprecedented quality, exceeding even the rigorous specifications established for the project. This is also true for the secondary mirror assembly. As a result of the better than anticipated image quality achieved by the current mirrors, some relaxation in our pointing control requirements can be accepted if necessary.

There have been discussions of contamination on the primary mirror over the past few months which I would like to put in proper perspective. Visible particulate accumulation, very fine dust, does exist on the primary mirror despite the most rigorous of contamination controls. Recent investigations have determined that 0.2 percent of the mirror surface contains particulate matter. This is well within the established one percent surface coverage criteria for launch; however, due to projected future accumulations, we plan to clean the mirror as a safeguard against any performance degradation resulting from particulate contamination. A low risk cleaning methodology for particulate contamination has been defined and cleaning will be conducted as late in the schedule as practical. Molecular contamination continues to be a concern, because even the smallest amount of molecular film on the optical surfaces will affect the reflectivity of the mirror in the ultraviolet region. We are investigating methods for testing for molecular contamination on the mirrors and will undertake testing and cleaning if needed. As a precaution against future contamination, we have recently decided that all structures that could be a source of this contamination will be vacuum baked.

The very precise alignment requirements, that must be maintained for many hours to collect the light from the faintest stars, dictated utilization of materials that would be essentially unchanged by extreme temperature variations. The temperature variations result from the sunlight and darkness periods of each orbit as well as the spacecraft's orientation to the sun. Total thermal requirements could not be defined until sufficient design was accomplished to develop refined thermal models. This challenge was ultimately met (March 1979) by the change from titanium to graphite-epoxy structures in critical parts of the Optical Telescope Assembly. Even with these materials, an extensive automatic heater system was also required to meet the thermal requirements. Graphite-epoxy is used for the focal plane structure, the metering truss which positions the secondary mirror relative to the primary mirror, structural components in the fine guidance sensors, and the shelf which positions the rate gyros relative to the focal plane structure. In addition, graphite-epoxy material is used for the optical benches of the science instruments. Graphite-epoxy material was a comparatively new material, as to precise design, and reliable data on strength and other properties were not available. These data had to be developed; also, the properties varied significantly from one piece to another, therefore, each piece had to be evaluated separately. These components have been completed now, except for the rate gyro shelf which is being assembled, and have been found to meet all our specifications. We did encounter a structural failure in a test article representing one of the structural mounting feet of the focal plane structure. A satisfactory repair, consisting of a titanium reinforcement was designed, fabricated, tested and installed on all of the focal plane structure feet.

The Fine Guidance Sensor, a key element of the Space Telescope Pointing Control System, has been and continues to be one of the most troublesome items in the Optical Telescope Assembly. The Fine Guidance Sensor enables the Pointing Control System to lock on to the desired object in space by way of two known guide stars, and to maintain that position with the extremely high accuracy of about a hundredth of an arc second for periods up to 24 hours. The Fine Guidance Sensor includes the Star Selector Servo, the Koesters' prism interferometer, photomultiplier tubes, and corrector optics. Control and signal processing is supplied by the Fine Guidance Electronics.

Several significant problems have been encountered in the development of the Fine Guidance Sensor. During the early development testing, the Star Selector Servo was mounted on a test bench that was to simulate the flight hardware. We found rather large vibrations that would have presented a significant problem for the Pointing Control System. Extensive analysis and testing recently completed have clearly demonstrated that these excessive oscillations were a result of the test setup and will not occur in the flight configuration.

A second significant problem was associated with the Koesters' prisms that generate the interferometric data needed to provide the pointing precision of the Space Telescope. Due to imperfections of some of the prisms, the initial characteristics of the interferometer were poor and not repeatable. Again, this would have led to great difficulties with the control system. Careful selection and extensive testing of the Koesters' prisms on hand showed that a satisfactory interferometer characteristic can be generated. This problem then became one of manufacturing adequate quantities of satisfactory Koesters' prisms. Additional studies are underway to resolve the cause of the manufacturing problems.

In view of these problems, it was decided to initiate total systems testing of the Fine Guidance Sensor as soon as possible. To accomplish this, the first flight unit was designated as an Engineering Model. I believe we now know how to solve the Fine Guidance Sensor problems, and the Engineering Model will allow testing of the system prior to the completion of the flight units.

Development of the latches to hold the science instruments and the Fine Guidance Sensors to the Focal Plane Structure with a precise alignment has also proven to be a major challenge of the Optical Telescope Assembly project. These 27 latches, consisting of two pieces each, maintain science instrument and Fine Guidance Sensor alignment within a few thousandths of an inch, isolate these components from heat transfer through the structure, and can be operated by an astronaut to provide on orbit instrument replacement capability. Development to these exacting requirements has been difficult. For example, galling was encountered when the latches were subjected to the expected launch environment. The coating was changed from aluminum oxide to a harder tungsten carbide cobalt coating, and recent dynamic testing of a group of latches at MSFC confirmed this new coating as acceptable. The first group of latches has now completed qualification testing with the new coating, and coating of flight latches is underway. Qualification testing of a second group of latches will continue in August 1983.

Fabrication of the major structural elements of the Optical Telescope Assembly has been completed by subcontractors and these items have been delivered to Perkin-Elmer at Danbury, Connecticut. Fabrication of the Ground Support Equipment and the Fine Guidance Electronics is progressing satisfactorily, and these are expected to be delivered to Perkin-Elmer on schedule for their respective need dates.

As the Optical Telescope Assembly flight hardware and design and manufacturing progressed, a much better understanding emerged of the special test equipment needed to accomplish the very demanding alignment and assembly tolerances. Therefore, the requirement for this additional special test equipment is now being incorporated into the program, thus driving a portion of the need for additional funding.

The primary technical challenge and schedule risk remaining to the Optical Telescope Assembly project are the successful completion of the Fine Guidance Sensor and its associated electronics and the successful assembly, alignment, and verification of the Optical Telescope Assembly system.

Technical and management problems that have been experienced by the Optical Telescope Assembly contractor, Perkin-Elmer, have resulted in significant schedule and cost impacts to the total program. Now, additional manpower resources have been applied to the project, senior management officials have been assigned to key project hardware elements and management control disciplines, and essential skills have been consolidated into dedicated teams to assure effective completion of specific hardware elements of the Optical Telescope Assembly. Over the past few months, substantial improvement has been made in both the management systems and performance at Perkin-Elmer. I will describe further changes at Perkin-Elmer in conjunction with the discussion of overall management changes.

Support Systems Module

The Support Systems Module being developed by the Lockheed Missiles and Space Company, Sunnyvale, California, provides the basic spacecraft services including pointing control, electrical power, data management and thermal control. In addition, it provides structural accommodations and the light shield for the Optical Telescope Assembly and the science instruments.

Assembly of all the large structural elements is now underway. The primary structure for the Equipment Section which houses the majority of the electronics and the Battery System has been completed, and the installation of doors and hardware mounting provisions is nearing completion. The primary structures for the Light Shield and Forward Shell which encompass the forward end of the Optical Telescope Assembly have also been completed, and the installation of light baffles in the Light Shield has been initiated. The assembly of the Aft Shroud primary structure which surrounds the science instruments and the Focal Plane Structure of the Optical Telescope Assembly is nearing completion.

Design of the major electronic assemblies has been completed, and these assemblies are now in the manufacturing and test phase.

The development of the Pointing Control System has made satisfactory progress in spite of some development problems. The sensitivity of the Pointing Control System can be illustrated by the fact, which was not fully appreciated in the initial stages of the program, that such items as changing a filter wheel position in one of the science instruments, operating the tape recorders, or tracking motions of the high gain antenna could cause unacceptable disturbance to a 25,000 pound spacecraft. To eliminate more critical disturbances, the Reaction Wheels, which are the primary means for maneuvering and pointing the Space Telescope, were retrofitted with bearings selected to reduce the vibration emanating from the Reaction Wheel into the

Space Telescope structure. Also, shrouds were mounted on the Rate Gyros to reduce mechanical noise contributed by the Rate Gyros assemblies resulting in a more stable control system. I believe that the actions taken will provide a Pointing Control System which will fulfill all its required functions.

Subcontract hardware deliveries continue to occur on or ahead of Support Systems Module assembly need dates. Major hardware deliveries during this year included: High Gain Antenna Masts, High Data Rate Transmitter, Tape Recorder, and the Fixed Head Star Tracker.

The Electrical Ground Support Equipment required in the verification of the Support Systems Module and the integrated Space Telescope is in the advanced stages of design and fabrication. This hardware is planned for installation and checkout late this year in the Space Telescope Vertical Assembly and Test Facility which was recently completed. Construction of the Scientific Instrument Receiving and Inspection Depot Facility has been started.

The detailed planning for the Support Systems Module checkout and the total Space Telescope assembly and verification is proceeding satisfactorily. To further assure the planned schedule, a number of Space Telescope subsystem tests have been advanced into the earlier Support Systems Module tests.

The most significant current Support Systems Module problem is associated with the Data Management System which encompasses the flight software and the Data Management Unit. The flight software has exceeded the memory utilization specification of the Data Management System flight computer. This specification was established to assure that 20% of the active memory capability would be available after launch to handle unexpected contingencies. Studies are under way to define a solution to this problem.

Two other problems being worked at this time are disturbance to the spacecraft stability caused by the High Gain Antenna Pointing System Motor and design errors found in the acceptance test of the Data Interface Units. Design solutions have been identified.

The primary technical challenge and schedule risk remaining for the Support Systems Module effort are the completion and integration of flight subsystems and ground support equipment, Space Telescope assembly and verification, and orbital checkout.

The overall progress of the Support Systems Module has been generally satisfactory. Although problems have been encountered, they have been of the type normally expected in a complex development project and, clearly, they have not been the pacing items in completing the Space Telescope development. Planning for the Space Telescope assembly and verification is well underway.

Systems Engineering and Integration

Systems Engineering and Integration is a function of paramount importance for a project as complex as the Space Telescope. It includes the establishment of consistent requirements for all levels of the project, the definition and control of all interfaces between project elements, and a verification that the designs of the hardware and software meet the requirements. Funding availability made it necessary to constrain the allocation of resources for System Engineering and Integration to a minimum essential level. As we approach the assembly and verification, increased emphasis is being given to this area to assure the physical and functional compatibility of all flight and ground control systems.

Solar Arrays

The Solar Arrays will provide all the electrical power for the Space Telescope while on-orbit. The roll-out, four-thousand-watt (specified power at the end of two years in orbit) Solar Arrays are being provided by the European Space Agency. The Solar Arrays are now in the final test phase and are ahead of schedule for Space Telescope assembly and verification. The Solar Array drive electronics, which is installed in the Support Systems Module Equipment Section, is designed to point the Solar Arrays at the sun, independent of Space Telescope maneuvering. The drive electronics will be delivered by the European Space Agency to Lockheed Missiles and Space Company this year, together with a development model solar array wing that will be used for mechanical and electrical compatibility checks. The test phase for the flight Solar Array wings will be completed during the first quarter of 1984. Significant problems associated with welding the solar cell interconnects and the Solar Array drive electronics encountered earlier in the project have been satisfactorily resolved by the European Space Agency. There are no known remaining problems or significant risks associated with the Solar Arrays.

Science Instruments

There are five science instruments, four being developed by the United States and one by the European Space Agency. Good progress has been made on all five instruments, and fabrication has been completed: One instrument is in final assembly, three have begun environmental acceptance testing, and one, the High Speed Photometer, is ready to begin the Verification/Acceptance Program at GSFC. The Verification/Acceptance Program is an electrical and software interface compatibility test involving all science instruments.

The Faint Object Spectrograph is a very versatile instrument that can obtain the spectra of extremely faint astronomical objects in the ultraviolet and visible wavebands. The assembled unit has completed about half the environmental test program at Martin Marietta Corporation, Denver, Colorado, and is scheduled to be shipped to GSFC in August 1983. During calibration, it was found that both Digicon detectors have lost performance. It is planned to replace at least one and, depending on additional tests, perhaps both detectors with existing spares before shipping the instrument to the Lockheed Missiles and Space Company.

The High Resolution Spectrograph will be able to use the full resolving power of the telescope. It has completed all environmental acceptance tests at the Ball Aerospace Division, Boulder, Colorado, and will be shipped to GSFC in June 1983. One of the Digicon detectors has exhibited excessive noise and will be replaced with an existing spare next year.

The High Speed Photometer is designed to measure the total light and its time variations from an object in space. This instrument is farthest along; it has been delivered from the University of Wisconsin to GSFC and is ready to begin the Verification/Acceptance Program.

The Wide Field/Planetary Camera will observe distant objects such as galaxies and quasars. High resolution images from the planetary camera will also permit detailed observations within our solar system. Following a few retrofits, the camera is now entering the environmental test program at the Jet Propulsion Laboratory, Pasadena, California. The instrument is scheduled to be shipped to GSFC in August 1983.

The Faint Object Camera is being built by the European Space Agency and will use the high spatial resolution of the telescope to observe the faintest stars. The instrument development suffered a setback last year when it was found that the photon detector tube had to be redesigned to be able to withstand the launch loads. The redesign has been completed and it satisfactorily passed vibration tests. There are some corona type problems on the flight camera that are being worked at this time. Delivery of the completed instrument to GSFC is scheduled for October 1983.

In summary, instrument development and testing have progressed to the point that verification and acceptance is now underway at GSFC. The remaining instruments are to be delivered by October 1983. Delivery of all instruments to the Lockheed Missiles and Space Company is scheduled for not later than June 1984 and will permit the planned exchange of certain instrument components and recalibration.

I will now address the Science Institute, Mission Operations, and Maintenance and Refurbishment. These have had their own unique development problems which have influenced the design of the Space Telescope, even though no major impacts have resulted.

Space Telescope Science Institute

The Science Institute will be the center for all aspects of the Space Telescope science activities, encompassing science planning and scheduling, operation of the science instruments and science data analysis. The Science Institute facility construction at Johns Hopkins University, Baltimore, Maryland, is completed and ready for full occupancy. Formal opening is scheduled for June 15, 1983. Staffing of senior management and technical positions has been completed, and the European Space Agency has begun filling its assigned positions at the Institute. In addition, the Science Institute is responsible for developing two critical pieces of the ground system; the Guide Star Selection System and the Science Data Analysis Software. The Guide Star Selection System Preliminary and Critical Design Reviews have been completed, and no major design deficiencies have been identified. The core of the Science Data Analysis Software will be nearing completion at year's end.

Mission Operations

The Mission Operations Ground System includes the Space Telescope Operations Control Center facilities at GSFC as well as all mission support software and systems other than those provided by the Science Institute. This provides the capabilities necessary to communicate, control and manage the spacecraft and science data. The system is well along in development. Critical Design Reviews on all elements have been satisfactorily completed. The Science Operations Ground System provides the capabilities necessary for science planning and scheduling, science observation support and science data processing. The software design is well advanced, and coding at the system level has been initiated. However, with the establishment of the Science Institute, the requirements have been better defined and have matured, and costs are expected to increase above prior projections. The technical requirements and related costs are currently being reviewed. The Science Operations Ground System development will be nearing completion at the end of 1983, and preparations for system interaction and test will be underway in early 1984.

Maintenance and Refurbishment

The Space Telescope Project was started at the time NASA was making a transition from the expendable vehicle era to the Space Shuttle, a change that would permit payload repair in orbit or retrieval if necessary. This new approach has led to many technical problems and reestimates of financial resources requirements during development that were not fully appreciated at the start of the program. A case in point is the difficulties encountered in the development of the latches, which I previously discussed.

The spacecraft design provides the capability for replacement of selected components. This capability will be limited to the smaller components such as batteries and rate gyros at the time of launch. The orbital replacement of science instruments and other large components will have to wait until all necessary space support equipment is available, approximately 2½ years after launch. Development of the Space Support Equipment was delayed deliberately for near-term cost considerations.

Status Summary

In summary, the Space Telescope is characterized by very stringent scientific and technical requirements. In satisfying these requirements, many problems of varying complexity have been encountered. We believe the problems are now understood and resolution of these is in hand. However, it is reasonable to expect additional problems as we begin to integrate all the Space Telescope systems and science instruments. Adequate provisions will be made for dealing with these kinds of problems in the new schedule and cost estimates to complete.

SCHEDULE AND BUDGET ASSESSMENT

The extreme complexity and demanding requirements, coupled with the inherent problems associated with some early project decisions, have made it extremely difficult to maintain schedules or to accurately predict cost requirements. Consequently, it became necessary to defer critical work to later years to stay within annual budgets. While the deferral of work provided a solution to our near-term problems, it could now be judged to have introduced too much schedule risk into a project of such complexity and importance. The difficulty in accurately predicting cost requirements also resulted in our having inadequate funds, or reserves, for coping with unanticipated technical and programmatic problems which further impacted our development schedule.

Our previous schedule baseline required delivery of the Optical Telescope Assembly to the Lockheed Missiles and Space Company for Space Telescope integration in December 1983, with a Space Telescope launch in the first half of 1985. It now appears that the Optical Telescope Assembly will be delivered in November 1984, with launch of the Space Telescope in June 1986.

The resolution of the development problems, the additional testing and spares included in the project rephasing to reduce schedule risk, increased systems engineering and integration effort introduced to facilitate project-wide integration and the extended development schedule have resulted in a sizeable increase in our development budget requirements. In FY83, $137.5M were authorized and appropriated for Space Telescope Development. It now appears that $182.5M will be required in FY83, an increase of $45M over that amount previously authorized and appropriated. It is now estimated that about $195M will be required in FY84, an increase of $75M over that contained in NASA's FY84 budget request. The new Optical Telescope Assembly deliveries and Space Telescope launch dates have been given to all participating organizations. Detailed revised schedules and revised cost to complete are being prepared and will be available later this summer.

The Operations and Maintenance/Refurbishment budget will be revised and rephased to be consistent with the new project schedule.

MANAGEMENT ASSESSMENT AND CHANGES

Our current schedule and cost problems began to significantly manifest themselves in mid-to-late 1982. The Optical Telescope Assembly was falling behind schedule at an increasing rate, and it was becoming more evident that the schedule could not be recovered and that additional manpower would be required to complete all remaining activities. I initiated a comprehensive review of the Optical Telescope Assembly at Perkin-Elmer in September 1982 with a number of the top management and technical directors from my Center. This assessment was directed to a lower level of activity than usually required at aerospace contractors. The assessment confirmed significant design and manufacturing problems with the Fine Guidance Sensor, latches and the special test equipment and the resultant overall schedule deterioration in the assembly operations for the Optical Telescope Assembly. In December 1982, I also initiated a programmatic review of the Support Systems Module at Lockheed to ascertain the technical status and to validate the cost and schedules being reported to MSFC. Since that time, there have been other Headquarters and Congressional review teams assessing the Space Telescope Project. The cost and schedule concerns and the need for major improvements at Perkin-Elmer that we reported to this Subcommittee in February 1983 have been confirmed. We reported at that time certain corrective actions that we had initiated. Subsequently, we have identified jointly with the NASA Office of Space Science and Applications additional changes needed to reduce technical and schedule risks for other elements of the project. For example, we rephased certain Support Systems Module testing at Lockheed, and we increased the Systems Engineering and Integration activity at Lockheed.

I will now describe changes in organizational structure and personnel that have been made.

Changes Implemented at the Marshall Space Flight Center

A new Manager for the Space Telescope Project Office was appointed. This appointment has made available to the Space Telescope Project Office, during the critical assembly and test phase, a highly successful hardware manager from the Shuttle Program.

The Project Manager was provided with an additional highly qualified senior individual as a deputy with full responsiblity for discharging all systems engineering activities at MSFC, GSFC and associate contractors. He is supported by a newly formed Systems Engineering Project Office and a strengthened Systems Engineering Organization within the MSFC Science and Engineering Directorate as well as an enhanced and dedicated Lockheed Systems Engineering organization. These systems engineering changes will significantly enhance the analytical integration, verification and operational planning for all elements of the Space Telescope Project and will increase the involvement of the science community in these most important activities.

Two subordinate offices to the Space Telescope Project Office, the Optical Telescope Assembly and Support Systems Module Project Offices, have been established with full authority for management of their respective systems, and each is supported by a dedicated procurement organization. This realignment allows the Space Telescope Project Manager to concentrate his full attention to directing the overall project.

Because of the concerns with the Optical Telescope Assembly, the newly appointed Optical Telescope Assembly Manager and his staff have been relocated on-site at the Perkin-Elmer facility to obtain visibility to a level of penetration not usually necessary for direction of the contractor efforts on a daily basis.

Changes Implemented at Perkin-Elmer

Perkin-Elmer appointed a new and experienced project manager to strengthen the management and programmatic disciplines in the Optical Telescope Assembly organization. Major realignments were made and the staffing of the Optical Telescope Assembly Project Office was increased to give greater emphasis to manufacturing, assembly, and test operations, and to improve visibility and control of schedules and cost. The executive vice president of Perkin-Elmer became the acting head of the Optical Group under which the Optical Telescope Assembly project is assigned. In this capacity he has made several other changes to strengthen its Space Telescope management structure. The appointment of a new executive over the Optical Group is anticipated momentarily.

Changes Implemented at Lockheed Missiles and Space Company

The Space Telescope systems engineering and integration function at Lockheed has been separated from the Support Systems Module activity to enhance support to MSFC's lead responsibility. Staffing has been increased and the function now reports directly to the Lockheed Vice President for NASA Programs.

Changes Implemented at the Goddard Space Flight Center

A new Deputy Director, Flight Projects for Space Telescope was appointed. Additional personnel have been assigned to his office and within the supporting GSFC organizations.

In conclusion, while the Space Telescope Project has presented considerable technical challenges, most of the challenges have been met successfully. Very substantial progress has been made on all of them, and we believe that we have developed a firm understanding of the job yet to be done. Furthermore, we believe we have the organization and virtually all the required talent in place to complete the job. Changes have been made both within NASA and the contractor organizations that will put the Project in a strong management posture. While other challenges may be encountered, we believe that we are in a position to meet them.

In retrospect, we might have made different decisions at earlier times in the Project and applied the available resources differently, if we had the benefit of the full insight currently available to us. However, that luxury is never available in real time. We are in the process of developing a revised and rephased program plan for schedules and cost which will embody the necessary reserves to accommodate normal development problems that can yet be expected. I am confident that the Project will be successfully completed and that all key science objectives will be met.

I recognize that the Space Telescope is the most significant science project undertaken by the Agency and the most difficult to implement, but the potential value to science and to our country is immeasurable. The Marshall Space Flight Center and the entire Space Telescope Team are committed to the successful completion of the Project.

Thank you.

APPENDIX A

SPACE TELESCOPE (ST) LEVEL I REQUIREMENTS

Minimum Performance Specifications for the ST

1. ST is a versatile, long-lifetime observatory; i.e., it must have the capability to accommodate a variety of scientific instruments and vary the complement of instruments with time.

2. The optical image should satisfy the following requirements in the visual and near-vacuum ultraviolet wavelengths: Resolution using the Rayleigh criterion for contrast of 0.10 arc-second; A full-width half-intensity diameter of 0.10 arc-second; 70% of the total energy of a stellar image must be contained within a radius of 0.10 arc-second.

3. The overall ST system must work efficiently down to wavelengths permitting the study of the Ly-α line at 1216 Å, requiring reaching to about 1150 Å. Likewise, it must allow efficient observations at infrared wavelengths longer than those readily accessible from the ground.

4. The system should accommodate at least four scientific instruments.

5. It must be capable of measuring objects appreciably fainter than those accessible from the ground. At the present this means going to about 27 M_v with a signal-to-noise ratio of 10 in 4 hours of observing time.

6. It must be capable of measuring extended sources of surface brightness of 25 M_v per square arc-second with a signal-to-noise ratio of 10 in 10 hours, with a resolution of at least 0.25 arc-second with a detector whose quantum efficiency is 10% and whose photometric accuracy is limited only by photoelectron statistics.

7. The ST must have the capability of using Scientific Instrument entrance apertures comparable in size to the image.

SPACE TELESCOPE CONFIGURATION

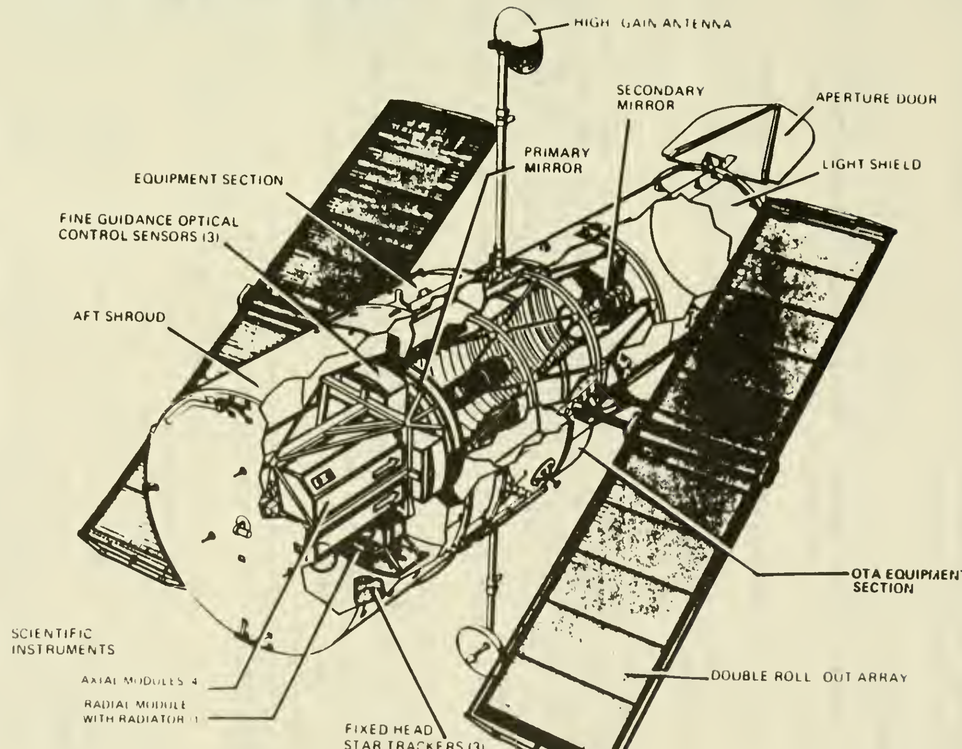

FIGURE 1

NASA MSFC

MSFC 7/80-ST 2821A

Questions submitted by Chairman Volkmer during the June 14, 1983, hearing at which Dr. Lucas testified on the Space Telescope.

QUESTION 1:

Dr. Lucas, the Space Telescope program was first rebaselined in December, 1980.

a. What were the reasons for that rebaseline?

b. What were the major actions taken as part of the December 1980 rebaseline?

ANSWER 1:

a. In 1980, the Space Telescope launch was rebaselined from late 1983 to the first half of 1985 due to technical difficulties which made the December, 1983, planned launch unattainable. Therefore, the development activities were rephased.

b. The major action taken as part of the rebaseline was slipping the launch from December, 1983, to the first half of 1985. Major milestones were also slipped consistent with the launch delay, and the contractor's activities were phased accordingly.

QUESTION 2:

Dr. Lucas, we understand that initially there were limits on the manpower at Marshall that could be assigned to the Space Telescope.

a. What was this limit? Why was such a limit imposed?

b. When did you first reclama this limit?

c. When was this manpower ceiling raised?

d. Are you under any limitations at the current time?

ANSWER 2:

a. Initially, it was believed that only approximately 100 Marshall Space Flight Center (MSFC) personnel would be required for overseeing the Space Telescope development activities. This belief was based on the perceived experience of the two associate contractors. However, as the design and development activities progressed, the need for additional manpower at MSFC was recognized.

b. There has been a steady increase in manpower from approximately 100 in 1978 to 250 at the present time.

c. The level of manpower working on Space Telescope has increased steadily over the years as the development technical difficulties were recognized.

d. There are no manpower limitations on Space Telescope at MSFC, other than that dictated by prudent resource management.

QUESTION 3:

We understand that the Marshall project office was initially organized "functionally" versus being "projectized by major subelement." Why was a "functional" organization used?

ANSWER 3:

The entire MSFC is a "functional" organization; therefore, the Space Telescope office was organized consistent with the rest of the Center.

QUESTION 4:

Dr. Lucas, what previous experience did Marshall have to undertake overall project management for a program such as the Space Telescope?

ANSWER 4:

MSFC has previously successfully managed large, complex projects of a similar nature involving multiple scientific instruments, aerospace contractor and scientific community interfaces, cooperative efforts with the European Space Agency, mission operations interfaces with the Goddard Space Flight Center and the Johnson Space Center and multiple hardware contractors. Most significant of these programs was the Skylab, Apollo Telescope Mount (ATM), High Energy Astronomy Observatories (HEAO), and Spacelab development. In addition, numerous smaller scientific projects have been successfully managed by MSFC.

QUESTION 5:

a. Dr. Lucas, would you agree that the "systems engineering" effort has been grossly understaffed in the past?

b. Does Marshall retain primary responsibility for systems engineering or does Lockheed have primary responsibility?

c. With regard to the systems engineering effort, how do you decide whether to retain a task in-house or to assign it to the contractor?

ANSWER 5:

a. There were shortages in critical areas, but not gross understaffing.

b. MSFC is responsible for accomplishment of Space Telescope systems engineering - Lockheed is under contract to support MSFC in this important activity.

c. The in-house versus contractor decisions on systems engineering task assignments are based on applicable experience, expertise, priorities, and timely access to required input data. However, all systems engineering tasks done by the contractor are monitored by experienced MSFC personnel.

QUESTION 6:

a. Dr. Lucas, how would you characterize the current assessment of technical difficulty compared with the assessment of technical difficulty when the program started?

b. Have there been technical surprises?

ANSWER 6:

a. The current assessment of the technical difficulties does not differ greatly from that at the beginning of the program. Some difficulties have been overcome and are no longer a risk; e.g., the primary mirror polishing and assembly. However, the total effort required to satisfy the extraordinary technical demands, such as the pointing system accuracy, turned out to be much greater than originally anticipated and planned.

b. Despite our special emphasis on critical systems from the outset, the extent of the technical difficulties and the time and effort required to solve them were not anticipated. Examples are the need to redesign the focal plane structure and the Fine Guidance Sensor optics as well as the full implications of a total contamination control.

QUESTION 7:

Dr. Lucas, to what do you attribute Marshall's failure to penetrate the Perkin-Elmer activities and identify the inadequate upper and mid-level management control at an earlier time?

ANSWER 7:

MSFC penetrated Perkin-Elmer to the extent normally required of an aerospace contractor. The Center normally monitors its contractors' activities to the major subsystem level. We did track Perkin-Elmer's progress at this level. and through the middle of 1982 the Optical Telescope Assembly schedule performance was about the same as we had experienced on other development programs of similar complexity. The current schedule problems began to significantly manifest themselves in the fall of 1982. The Optical Telescope Assembly was falling behind schedule at an increasing rate, and it was becoming more evident that the schedule could not be recovered and additional resources would be required to complete the remaining activities.

In late 1982, I initiated a comprehensive review of the Optical Telescope Assembly at Perkin-Elmer with a number of the top management and technical directors from MSFC. This assessment was directed to the major component or assembly level of activity which is not usually required at aerospace contractors. That assessment confirmed significant design and manufacturing problems with the Fine Guidance Sensor, with the latches, and with some special deterioration. The preliminary results of these reviews were reported to this Subcommittee in February, 1983.

We are continuing to monitor Perkin-Elmer's progress at the major component level with the MSFC project office personnel located at the Perkin-Elmer plant in Danbury, Connecticut.

QUESTION 8:

a. Dr. Lucas, what is your assessment of the manner in which NASA Headquarters has exercised overall management responsibility for the Space Telescope program?

b. Have there been major disagreements over program direction or resource requirements?

c. How would you characterize the lines of communications between Marshall and Headquarters?

ANSWER 8:

a. NASA Headquarters has exercised its overall management responsibilities for the Space Telescope in essentially the same manner as it has done for other space science and applications projects however, like MSFC, the level of staffing of the NASA Headquarters project office may have limited its ability to effectively overview and assess project progress and problems.

b. There have been no major disagreements over program direction or resource requirements.

c. NASA Headquarters has overall responsibility for managing and directing all aspects of the Space Telescope project. MSFC has project management, responsibility for all Space Telescope project hardware development activities, and for maintenance and refurbishment preparation activities. In this capacity, the MSFC project office reports directly to the NASA Headquarters on all project related matters. Thus, there is direct line of communication between Marshall and Headquarters.

QUESTION 9:

What are the major lessons learned from the Space Telescope development experience?

ANSWER 9:

I think we have learned the importance of clearly defining a program before we begin. I believe we did define this program in its overall concept before we began; however, we underestimated the technical complexity of the Space Telescope development.

QUESTION 10:

a. Could you elaborate on the contamination problems--both molecular and particulate?

b. What is being done to minimize the chances of contamination since more than than three years remain before launch?

c. How will you handle the contamination problem during refurbishment? Has this been carefully thought out?

ANSWER 10:

a. The contamination problem of the most concern and the one that has received the greatest attention is that of particulate accumulation on the primary mirror. Since the mirror was coated in December, 1981, particulates visible to the eye have accumulated during the various test and assembly operations perforated in controlled environments. Measurements have been made to determine the size and density of these particles. The results have been compared to the acceptance criterion that was developed based on the scientific requirement specified by the Science Working Group. This comparison shows that there is a margin between the particulate level presently on the mirror and the acceptance criterion. However, because of the concern of continued particular contamination, the mirror will be cleaned as late as possible prior to launch. The techniques and procedures for doing this are now being developed. It is planned that this cleaning operation will be performed just prior to integration with the secondary mirror structure.

In addition to particulate contamination, the question of molecular contamination of the primary mirror has been raised. Witness samples that were coated with the mirror and which are, in all probability, reasonable representations of the state of cleanliness of the overall primary mirror have been measured and show no loss in reflectivity. This indicates that, if there were any molecular accumulation, it did not affect the coating performance. However, because of the extreme criticality of the primary mirror reflectivity, a direct reflectance measurement of the actual mirror is planned to verify its optical performance.

Based on the measurements and analyses that have been made to date, the primary mirror meets its performance requirements. Stringent contamination control measures will continue to be taken to assure that the mirror's performance is not degraded below the acceptable limits.

b. All aspects of the Space Telescope contamination control plan are being reexamined to ensure the adequacy of the plan and to ensure that procedures are in place to assure its effective implementation. Changes to the plan that have already been made include the vacuum bakeout of all hardware elements with a direct view of the mirrors to minimize the potential for molecular contamination; more stringent control and monitoring of work area, clean room, transportation, and storage environment; double bagging of hardware after cleaning and bakeout; and increased frequency of inspections and audits of contamination related activities.

A cover to provide increased protection for the primary mirror during assembly and verification is being investigated. A conceptual design is presently being evaluated using a scale model of the Optical Telescope Assembly. Should this investigation show that such a cover is feasible and would be effective in protecting the mirror, direction will be given for its implementation.

c. An analysis of the types and source of contamination that could potentially pose a threat to the Space Telescope during on-orbit refurbishment operations has been initiated but has not been completed. In addition, techniques and procedures for minimizing these sources are being reviewed. For example, the Johnson Space Center is developing a handling approach that will minimize the potential for contamination due to the orbiter indigenous environment. Also, the aperture door will be closed and the solar arrays rolled up during refurbishment. All hardware and materials will be cleaned, vacuum baked, and double bagged to ensure their cleanliness. In summary, all refurbishment operations, including hardware and materials used will be evaluated for contamination potential and appropriate steps will be taken to preclude a source of either particulate or molecular contaminants.

QUESTION 11:

Could you elaborate on the technical difficulties which have been experienced with the Fine Guidance Sensors?

ANSWER 11:

The principal Fine Guidance Sensor (FGS) technical difficulties experienced to date have been associated with developing a state-of-the-art instrument of substantial complexity with rigorous tolerance requirements. More specifically:

1. The design of the optical elements is extremely complex and required early major redesign to achieve requirements.

2. Difficulties during the manufacture of very precise Koesters' prisms have required extensive analysis and additional manufacturing efforts.

3. The extreme stability and accuracy requirements of the servo system has resulted in numerous development problems.

4. The optical bench stability requirements have necessitated extensive development efforts and ultimately the use of graphite-epoxy structures.

5. The development of the electronics and power system for the FGS has experienced difficulties in power supply, software, and logic development.

6. Extremely small tolerances required for verification of FGS alignment accuracies have resulted in difficulties in the definition of the required test equipment.

QUESTION 12:

a. Dr. Lucas, how does Marshall fulfill its responsibilities of oversight over the Goddard Space Flight Center Space Telescope activities?

b. Does Marshall have good visibility into the Goddard activities?

ANSWER 12:

a. MSFC has management responsibility for all aspects of the Space Telescope. GSFC has responsibility for the science instrument development and operations and, as such, is responsible to MSFC in the execution of these responsibilities. Oversight of the Goddard Space Flight Center's Space Telescope activities is accomplished by clear delineation of responsibilities and appropriate visibility of progress and problems. Joint quarterly reviews of the entire project are held to review progress and problems for all project elements and to assist in the coordination and integration of all participating organizations.

b. Marshall has good visibility into Goddard's Space Telescope activities.

QUESTION 13:

a. What will be the role of Marshall, if any, during the operational phase of the Space Telescope program?

b. Will Marshall have responsibility for refurbishment and maintenance?

ANSWER 13:

a. MSFC has overall project management responsibility for the Space Telescope, which includes development, operations, and maintenance and refurbishment. During the operational phase, overall management responsibility is expected to remain at MSFC, with GSFC having direct responsibility for science operations.

b. Yes, MSFC will have direct management responsibility for future maintenance and refurbishment activities.

QUESTION 14:

a. Could you describe the award fee structure for both associate contractors (Lockheed and Perkin-Elmer)?

b. Who is the responsible official for establishing the award fee?

ANSWER 14:

a. The award fee structures for Lockheed and Perkin-Elmer are the same. Each contractor is evaluated periodically, generally semi-annually, for attainment of contract commitments during that specific award fee period. The award fee is based on performance under three major criteria which are: technical and schedule achievement, cost performance and business management.

b. The MSFC Deputy Center Director, as the fee determination official, has responsibility for establishing award fees.

QUESTION 15:

a. With regard to the Perkin-Elmer contract award fee, what amount of fee has Perkin-Elmer earned compared to what has been available?

b. Is award fee based on schedule, cost, technical performance, or on what basis?

ANSWER 15:

a. Through November 30, 1983, Perkin-Elmer earned $2,568,618 of the available $4,894,227 award fee. The earned fee equates to 52 percent of the available award fee.

b. The award fee is based on technical and schedule achievement, cost performance and business management. The bulk of the award fee earned to date by Perkin-Elmer is for technical achievement.

QUESTION 16:

With regard to the Lockheed contract award fee, what amount of fee has Perkin-Elmer earned compared to the maximum that was available?

ANSWER 16:

We believe the question pertains to Lockheed rather than Perkin-Elmer. Through September 30, 1982, Lockheed earned $6,397,039 of the available $7,052,424 award fee. The earned fee equates to 91 percent of the available award fee.

QUESTION 17:

a. How would you characterize Perkin-Elmer attitude toward making needed management changes?

b. Are there outstanding issues between Marshall and Perkin-Elmer related to management structure or approach?

ANSWER 17:

a. Initially, Perkin-Elmer was reluctant to adjust its management structure. Since the first of this year, however, Perkin-Elmer management has displayed the willingness and ability to act decisively to modify company and project management structures.

b. While the effectiveness of some of Perkin-Elmer's recent management changes have yet to be demonstrated, there are no outstanding issues between Marshall and Perkin-Elmer related to management structure or approach.

QUESTION 18:

Could you elaborate on the organizational changes which have been made at both Marshall and the associate contractors?

ANSWER 18:

A number of changes have been made in both the organization and management of the Space Telescope project to provide improved working relationships, to better define management responsibilities of major components; to provide greater contractor management involvement and visibility; and to assure early identification of potential problem areas. Discussed below are the major changes made the MSFC and the associate contractors.

Marshall Space Flight Center (MSFC)

A new manager, Mr. James Odom, was appointed to head the Space Telescope Project Office. His appointment has made available to the Space Telescope Project Office, during the critical assembly and test phase, a highly successful hardware manager form the Shuttle program, Mr. Odom was manager of the Shuttle External Tank project.

Mr. Odom was provided with a highly qualified senior individual as a deputy with full responsibility for discharging all systems engineering activities at MSFC, GSFC and the associate contractors. The person appointed to this position has had significant technical an managerial assignments at MSFC, and come to this new position from an assignments at MSFC, and comes to this new position from an assignment as the director of a major laboratory. He is supported by a newly formed Systems Engineering Project Office and a strengthened systems engineering organization within the MSFC Science and Engineering Directorate as well as an enhanced and dedicated Lockheed systems engineering organization. These systems engineering changes will significantly enhance the analytical integration, verification and operational planning for all elements of the Space Telescope project and will increase the involvement of the science community in these important activities.

Two subordinate offices to the Space Telescope Project Office, the Optical Telescope Assembly and Support Systems Module Project Office, have been established with full authority for management of their respective systems, and each is supported by a dedicated procurement organization. This realignment relieves the Space Telescope Project Manager from the day-to-day direction of the Optical Telescope Assembly and Support Systems Module projects, and allows him to concentrate his full attention on the management of the overall project.

The newly appointed Optical Telescope Assembly Manager and his staff have been relocated on-site at the Perkin-Elmer facility to obtain visibility to a level of penetration not usually necessary for direction of the contractor efforts on a daily basis. This relocation has contributed significantly to the improvement of the contractor's performance.

Perkin-Elmer

Perkin-Elmer appointed a new and experienced project manager to strengthened the management and programmatic disciplines in the Optical Telescope Assembly organization. Major realignments were made and the staffing of the Optical Telescope Assembly Project Office was increased to give greater emphasis to manufacturing, assembly, and test operations, and to improve visibility and control of schedules and cost. The executive vice president of Perkin-Elmer became the acting head of the Optical Group under which the Optical Telescope Assembly project is assigned. In this capacity, he has made several other changes to strengthen the Space Telescope management structure. Since my June 14, 1983, testimony, a new executive, Mr. William W. Chorske, has been named as vice president in charge of the Optical Group at Perkin Elmer.

Lockheed Missiles and Space Company

The Space Telescope systems engineering and integration function at Lockheed has been separated from the Support Systems Module activity to enhance the support to MSFC. Staffing has been increased and the function now reports directly to the Lockheed vice president for NASA progress, which provides for much greater visibility by top management at Lockheed as well as increased emphasis on Space Telescope within Lockheed.

QUESTION 19:

a. Are you aware of any contractor mischarging which way have occurred?

b. Have you undertaken any investigations to look for contractor mischarging?

ANSWER 19:

a. Not in the context of intentional mischarging designed to benefit the contractors. Recognizing that recording and accounting costs are not exact sciences, there have been occasional disagreements between Government auditors and contractor accountants as to accounting methodologies and incurrence of costs. These disagreements have always been equitably resolved.

b. We have had no reason to undertake any investigations to look for contractor mischarging. However, NASA routinely utilizes Defense Contract Audit Agency resident auditors in each contractor's plant. These auditors perform continuing audits of all costs incurred and, in addition, perform periodic and random tests of contractor accounting practices and systems to validate the propriety of contractor charges.

QUESTION 20:

Are the scientific requirements being descoped in any way?

ANSWER 20:

The Space Telescope science performances are not being descoped in any way.

QUESTION 21:

If molecular contamination were to occur, could such contamination be removed? Is such a procedure well understood? What would be involved?

ANSWER 21:

Should molecular contamination be verified, it would result in a significant impact to the program. There is currently no established process for removal of molecular contamination without contacting the mirror surface, and that carries with it substantial risk of damage to the mirror coating. Should molecular cleaning become necessary, however, one would develop a least risk methodology based upon the identify and amount of contamination and attempt the cleaning. Failing that, it might be necessary to remove the mirror from the support ring, remove all hardware and coating from the mirror, and subject it to recoating.

QUESTION 22:

What alternatives are under consideration to provide a solution to the lack of active memory capability?

ANSWER 22:

Both hardware and software alternatives are being considered to provide sufficient active memory capability such as:

1. The use of an existing backup memory module to increase the normal computer base size by 8192 locations.

2. Add on an auxiliary random access memory device for programmable memory and stored program commands.

3. Modify the data management unit to process programmable telemetry.

4. Add on an interface box between the data interface unit and the high gain antenna to accomplish antenna pointing.

5. Add a second DF-224 computer.

QUESTION 23:

What are the additional costs associated with the decision to use the first Fine Guidance Sensor as an engineering model?

ANSWER 23:

The additional cost associated with the use of the first flight unit of the Fine Guidance Sensor as an engineering model will be approximately $4.5 million.

QUESTION 24:

If you could do it again, would you have as many cooks in the kitchen, that is, would there be as many contractors and centers involved?

ANSWER 24:

Although there was good logic for the current Space Telescope contractural arrangements, I believe the project could possibly have been accomplished more effectively under a single prime contractor arrangement. Having two centers involved in the management of the Space Telescope development (MSFC for the support systems module and optical telescope assembly, and GSFC for the science instruments) has not, however, been a major problem.

QUESTION 25:

If Perkin-Elmer has been able to follow the original schedule, would Lockheed have had any trouble in meeting the original schedule?

ANSWER 25:

We believe the Lockheed development effort has been on schedule, however, we believe there were certainly some potential risks to Lockheed completing their portion of the Space Telescope development activities on schedule.

QUESTION 26:

Would an early emphasis on systems engineering have minimized the effect of some of these problems?

ANSWER 26:

Inadequate systems engineering is not considered to be the cause of our current problems. It is possible, however, that had more emphasis been placed on systems engineering, we may have identified certain problems earlier, thus minimizing the schedule impact currently being encountered.

QUESTION 27:

If the funding shifts had resulted in cutting the support system module at Lockheed, rather than the systems engineering support, what would have been the impacts?

ANSWER 27:

More systems engineering effort may have equipped us to better anticipate development problems as driven by requirements. However, many problems do not fully manifest themselves until the hardware development and test phase is well underway. It is my belief that the current situation has been driven more by the stringent technical requirements to meet program objectives than by the lack of systems engineering efforts.

Mr. VOLKMER. Thank you very much, Dr. Lucas.

We will now proceed with questioning under the 5-minute rule. I recognize the gentleman from New Mexico.

Mr. LUJAN. Thank you, Mr. Chairman.

Do we have a cost and time, for when and how much?

Dr. LUCAS. We are working toward the optical telescope assembly being delivered to Lockheed in November 1984, with a June 1986 launch. The total runout cost under consideration now is in the $1.1–$1.2 billion range; however, we will be able to provide better defined estimates about the end of July/August timeframe.

[The information follows:]

The estimated preliminary total runout cost is on the order of $1.1–$1.2 billion; however, we will be able to provide a better defined estimate about the end of July/August timeframe.

Mr. VOLKMER. Would the gentleman yield for just a moment?

Mr. LUJAN. Certainly.

Mr. VOLKMER. I would like first, without objection, unless someone objects, to give permission for filming to proceed, if they so desire, unless someone on the committee objects. You may proceed.

Thank you, Mr. Lujan.

Mr. LUJAN. You can't give us a figure?

Dr. LUCAS. No sir, our reviews are not yet completed.

Mr. LUJAN. Can you give us a ballpark figure?

Dr. LUCAS. I think the ballpark figure is on the order of $1.1 to $1.2 billion.

Mr. LUJAN. What did it start off as?

Dr. LUCAS. The original estimate was $435 million or a range of $425–$475 million in fiscal year 1978 dollars which is about $610 million in real year dollars. Therefore, the $1.1–$1.2 billion range mentioned earlier should be compared to a $610 million funding level, if one is to compare apples and apples.

Mr. LUJAN. So we have 2½ times that?

Dr. LUCAS. The $425 to $475 million estimate excluded inflation.

Mr. LUJAN. Don't you take inflation into account when you look at the overall cost? You say this program is going to cost us $450 million. Don't you look ahead 2 or 3 or 5 years as to what the inflation factor is going to be?

Dr. LUCAS. The original estimates were in 1978 dollars and so stated at the time.

Mr. VOLKMER. Would the gentleman yield on that point for just a moment?

Mr. LUJAN. Sure.

Mr. VOLKMER. It is more on the revised schedule than it is on the cost. In your statement you say that detailed revised schedules and revised cost to complete are being prepared and will be available later this summer. We know you are giving us the completion date, but you don't yet have the detailed schedules of that?

Dr. LUCAS. Mr. Chairman, what we are planning to do there is to make sure that we balance the entire program. Perkin-Elmer has committed to delivery of the OTA in November 1984. Assuming the receipt of the OTA by Lockheed in November 1984, we anticipate we can launch the space telescope in June 1986. However, there are many other elements that play into preparation for the launch, and these have to be scheduled most efficiently so that they don't get ready before we need them and use up costs unnecessarily. That is what I mean by the revised detailed schedules. I don't think the OTA delivery and launch schedule that we are giving to you now will change, and I referred to the costs that are now being estimated assuming these higher level schedule dates.

Mr. Volkmer. You don't believe there is any further unanticipated surprises that will occur within the integration of the support module with the vehicle itself or the optical telescope with the support module? All those things have to take place yet, do they not?

Dr. Lucas. It would be abnormal, Mr. Chairman, if we didn't encounter any problems. We will encounter some problems, but I believe the schedule that we have outlined and the costs that we will present to you will include enough contingency to cover the normal kinds of problems associated with this activity. I can't say that we won't have more unanticipated problems. We have had a very thorough evaluation of the program with the best people available to us, and based upon that assessment, we believe that we understand the program and have made prudent revisions to our plans.

Mr. Volkmer. Thank you very much.

I yield back to the gentleman from New Mexico.

Mr. Lujan. Thank you, Mr. Chairman.

I have been maybe unduly critical of the contractor in various hearings that we have had, just laying the whole thing right on their lap, that I suppose is not quite fair to say: well, because of you this whole program didn't go on. Let me see if there isn't any shared responsibility for those delays.

The contract was issued in 1979. It was rebaselined in 1980. But you tell us when you found out something was wrong in 1982, then we got hot on their trail. Didn't you have any indication that you had some problems when you rebaselined it in 1980?

Dr. Lucas. Mr. Lujan, Perkin-Elmer has not been precisely on schedule since very early in the program. We did the whole ST program during the fiscal year 1982 budget formulation process. The schedule tracking looked pretty good up through about the middle of 1982 but the loss of schedule—that is, the falling behind of schedule—began to accelerate in August. That is the time we became concerned——

Mr. Lujan. Is that when deliveries were due?

Dr. Lucas. No, it was not when deliveries were due, but I think part of that had to do with our looking in and finding out that the contractor's plans would not support the type of schedule that he was giving to us. When you get nearer to the hardware stage, you normally find what your problems are.

Mr. Lujan. Were there changes in requirements during this time?

Dr. Lucas. No, sir, there were no changes in requirements that would have caused this.

Mr. Lujan. What we are coming up with is pretty much what we originally thought we needed? That has held pretty true and that is what we are going to get when it finally is up there?

Dr. Lucas. We are still working to the same specifications we started with. I have no reason to believe we won't meet those. We haven't increased or decreased the specifications. However, I think in all fairness one must say that virtually every aspect of the program with which Perkin-Elmer deals has been on the cutting edge of technology. When you implement that kind of a program, you have some problems, and they have had some.

Mr. LUJAN. Are there backup parts to this whole telescope?

Dr. LUCAS. Yes, sir, there have been. As I mentioned earlier in the testimony, we thought the primary mirror was going to be the great problem. It was on the critical path in the early days of the program, and we were sufficiently concerned about that to have started a backup mirror polishing at Eastman-Kodak. As a matter of fact, that backup mirror polishing was completed; however, it was not coated, and it is now in storage. It was stopped at the point when it was evident that Perkin-Elmer was going to be successful in their polishing of its mirror. So, we had a backup at that particular point.

We have had other backups along the way. For example, when we encountered the latch problem last fall, we started a backup at Lockheed. It subsequently has been stopped because of the success we had with the mainstream latches.

Mr. LUJAN. It is a different system that you try when you start putting together the backups?

Dr. LUCAS. Do you mean for the mirror?

Mr. LUJAN. Both that and the latches.

Dr. LUCAS. In the case of the mirror, we used the same kind of a mirror, but we used a polishing technique that was different from what Perkin-Elmer was using. In the case of the latches, we were considering a different kind of coating than Perkin-Elmer would be using. Actually, Perkin-Elmer changed the coating from an aluminum oxide to a tungsten carbide cobalt coating. That seems to have solved that problem.

Mr. LUJAN. Suppose somebody dropped the mirror?

Mr. VOLKMER. Just forget it.

Mr. LUJAN. Well, it wouldn't be forget the whole project. You have the other backup. Can you kind of move along with it?

Dr. LUCAS. That would be a very great blow to the program. We just are not going to drop that mirror. The mirror is now mounted. I think if we were going to drop it, it would have already been dropped. It is now mounted in the flight ring. One of the problems in handling that mirror, was that the handling fixtures had to be treated with such great care. I will tell you, I had a sleepless night as they transported that mirror from Danbury, over the roads of Connecticut, to have it put in the chamber and coated.

If such an unlikely and unthinkable event happened, that we would drop the mirror and break it, we could use the backup mirror; but, it would still have to be coated and go through all this very careful alignment and mounting procedure that we already have behind us in the primary mirror.

Mr. LUJAN. To get rid of this accumulation that will happen between now and the time of launch—I gather that is what you were talking about, that it gets film on it or whatever—what do you have to do? Grind it back again, a little vinegar and water, or what?

Dr. LUCAS. To remove particulate contamination, the plan that is now being considered is that we would turn it upside down and very carefully, at the proper angle, blow air across the mirror from the bottom side to rid it of the particulate contamination.

Mr. LUJAN. That is just dust and specks on it that gather?

Dr. LUCAS. Yes, it is dust that covers two-tenths of 1 percent of the surface, so it is not as if it is a dusty road. It does have dust particles that are of great concern to astronomers, but it is not a great deal of dust in terms that we normally think of.

Mr. LUJAN. Is it in some case or something so that it is not collecting dust?

Dr. LUCAS. It is covered presently in a 10,000 K clean room.

Mr. LUJAN. How about in transportation?

Dr. LUCAS. It will be encased in such a way as not to be subject to dust accumulation at that time.

Mr. LUJAN. Thank you, Mr. Chairman.

Mr. VOLKMER. The Chair will now recognize the gentleman from Washington.

Mr. CHANDLER. Thank you, Mr. Chairman.

Dr. Lucas, to follow up on the questions of the gentleman from New Mexico, I understood that despite the fact that, as you describe it, only two-tenths of 1 percent of the surface of the mirror is covered by dust, that whatever accumulation was on it was going to result in the mirror only being about 80 percent of effectiveness.

Is that incorrect? Did I read that incorrectly?

Dr. LUCAS. That is incorrect. I have heard that statement, too. Jean Olivier, could you comment on the effect of the particulate contamination we now have?

Mr. OLIVIER. We have just recently completed a very detailed evaluation of the particulate contamination on the mirror by actually photographing it at very close scale and measuring the particle size. The importance of this is that the size of the particle has a direct bearing on the scattered light effect on the image that is formed. It is something roughly proportionate to of the fourth power of the diameter of the particle. Therefore, we are very concerned particularly about any larger particle that would be on it.

We have completed this evaluation, and we have agreed with the science community on criteria which would be acceptable. We have successfully translated this into a derived engineering criteria on particle count distribution. We found, just recently, in the completion of the reduction of this data that we are probably within a factor of less than two of being up to this limit. That means that we have a margin that we can deal with between now and the time of launch, which is a very important factor because we must make sure that we do not continue, to accumulate dust on this mirror because we have another few years ahead of us before launch.

We have worked this problem to the point that we feel we do understand it. Although we have not exceeded the amount of particulate contamination which we believe can tolerate, we still plan to clean the mirror in this very benign way by blowing air over it. That gives more margin, so that we can make sure that we do not exceed, in the years to come before launch, any unacceptable build-up of particulate contamination.

Mr. CHANDLER. For a very lay layman, back to the percentage of effectiveness terms, the 80 percent isn't the number. What is?

Mr. OLIVIER. I would estimate from a particulate standpoint we have built up roughly 25 percent of the allowable buildup of particulates before we could begin to affect science.

I don't understand exactly the context in which the 80 percent was brought up. They may have been referring to molecular contamination. Molecular contamination would be that kind of contamination which would affect the throughput of the mirror. It would reduce the reflectivity, if you will. That has been measured and monitored by indirect means. By that I mean we have a number of small witness samples that were coated at the same time the mirror was coated. These witness samples have been kept in close proximity of the mirror throughout its whole lifetime. We have been continually monitoring the reflectivity of these small samples. The contractual requirement at Perkin-Elmer was that in the far UV, that this mirror have a 70-percent reflectivity. That reflectivity was measured at about 78 percent, so we are above specification. We have constantly monitored these witness samples.

One of the questions that has been raised is, "If you are not measuring directly on the mirror, how do you know the witness samples represent the mirror?" That is a good question. We are confident of the witness samples, but we do plan to measure the mirror in the very near future, just to confirm the approach we have taken.

Mr. CHANDLER. I think those reflectivity numbers must have been the ones that Mr. Lucas and I were reading.

You made a statement a moment ago, Mr. Lucas, that you felt that one of the problems throughout this was that "we are on the cutting edge of technology." From what little I have been able to learn about it, I would certainly agree.

How much of that fact is the problem and how much of it do you blame on mismanagement or whatever else you would like to determine? Obviously you are breaking some new ground here. Maybe you could also, for the benefit of the committee, compare it to similar technological groundbreaking projects and its complexity, if that is a valid comparison to make.

Dr. LUCAS. It is a very difficult comparison to make. We haven't encountered a telescope of this complexity before. I think the size and the precision of this telescope exceeds anything that has ever been done before. I really don't have a base to compare it to. I think a very substantial part of the problems that we have encountered have been associated with these technical difficulties. The management I suppose comes into play in the response to technical difficulties that one has. I think a very significant part of the problem is associated with these technical difficulties.

Mr. CHANDLER. Perhaps you underestimated the technical difficulties to begin with.

Dr. LUCAS. One would have to admit that we did underestimate the technical difficulties from the outset.

Mr. CHANDLER. Thank you, Mr. Chairman. I have no other questions.

Mr. VOLKMER. The gentleman from Florida?

Mr. MACKAY. Thank you, Mr. Chairman.

I am sorry. I came in late. Who was the general contractor?

Dr. LUCAS. I beg your pardon?

Mr. VOLKMER. The question is who is the general contractor.

Mr. MACKAY. There are two associate contractors——

Dr. LUCAS. There is no general contractor. It was decided at the outset that we would have two associate contractors, and it is the responsibility of the Marshall Space Flight Center to pull these activities together.

Mr. MACKAY. I noticed there were a number of management changes at the top management level. If the problem came about because of unforeseen technical difficulties, it would have looked like there were some scapegoats somewhere. I am saying it looks to me like there was a combination of perhaps not enough priority and the technical difficulties——

Dr. LUCAS. At the Marshall Space Flight Center, the original project manager left the center and a second project manager was appointed to replace him. He served until the appointment of Mr. Odom just a few months ago.

At the Lockheed Missiles and Space Co., the original project manager at that plant is now vice president for NASA programs and has that project manager under his management. There has been continuity there.

At Perkin-Elmer there have been, I believe three management changes. The original project manager was changed at a time that I think was appropriate when we had advanced from the early technology to the point of manufacturing. A manager with a manufacturing background was appointed as project manager, and then he was replaced with the current manager, who was selected last August, and who I think is the kind of manager that Perkin-Elmer had been looking for.

Mr. MACKAY. Do you feel that the Marshall Space Flight Center was sufficiently on top of the problems at Perkin-Elmer, or were there surprises there?

Dr. LUCAS. The Marshall Space Flight Center was tracking the ST program very carefully. We knew week-to-week the progress of the Perkin-Elmer Co. in achieving the schedules that they had committed to us. In a project of this nature, there are several levels of activity. We call them levels 1, 2, and 3. Level 1 is the space telescope, level 2 is the OTA and SSM and level 3 is the subsystem level. Normally we track to level 3. Because of the continuing problems in making schedules, we made an assessment last fall at level 4. We took people who were familiar with scheduling programs into the plant, on the floor, and found out what was going to have to happen in order that they could meet the schedules that they were committing to us.

We are now tracking at that level, which as I mentioned before you came in, is unusual in the management of an aerospace contractor.

Mr. MACKAY. Thank you, Mr. Chairman.

Mr. VOLKMER. Thank you.

I have several questions. Maybe I can get finished before we vote on this vote.

One thing I noticed in your statement is you lead me to believe that some of the problems caused by deferring work to later years is staying within your annual budget. I would like to know—if you can't tell me right now, all right, because I am going to give you other questions that I am going to ask you to answer in writing—what work was deferred and how that impacted on both time and cost.

Dr. LUCAS. To give you a complete list, Mr. Chairman, I would have to request permission to submit that for the record.

Mr. VOLKMER. Yes, I would like to have that, when that started and how far back it goes. I am fairly new on the scene on this work, just knowing recently about it, and it appears to me that things like the gentleman from New Mexico brought out, that in 1980 there was some question, but I would like to know when that all came about.

[The information follows:]

During fiscal year 1982, the Space Telescope project experienced cost and schedule problems which exceeded the amount budgeted in fiscal year 1982 and in order to remain within the fiscal year 1982 Space Telescope budget, it was necessary to defer approximately $10 million of OTA work and approximately $6 million of SSM work into fiscal year 1983. These deferrals, coupled with a 2-month schedule slip, impacted the runout cost. During early fiscal year 1983, the project schedules continued to slip, necessitating a rebaselining of the Space Telescope project, which is currently in process.

OTA Deferrals—fiscal year 1982 to fiscal year 1983: Approximately $10 million.

Secondary Mirror Assembly; Optical Control Sensor; Fine Guidance Electronics/Optical Control Electronics; Action Control Electronics; Electrical Power/Thermal Control Electronics Sensor; Electronics Assembly, and Main Baffle.

SSM Deferrals—fiscal year 1982 to fiscal year 1983: Approximately $6 million.

Structures Manufacturing; and Electrical Ground Support Equipment Engineering.

Mr. VOLKMER. Do you see any problems with the integration of the OTA into the support module?

Dr. LUCAS. The integration of the OTA into the support system module will certainly be a challenge. Adequate plans for this integration are in the process of being made. I would expect that there would be some problems associated with that, but I think we will have enough contingency in our schedule to handle any of the normal problems that come up. I base my confidence on the fact that we do have very carefully described interfaces between the various components that have to come together.

Mr. VOLKMER. You don't anticipate any funding shortfall or anything else along that line?

Dr. LUCAS. No, sir. We have, in the process of this replanning, increased the time scheduled for that. For example, we had programmed eleven months for the assembly and verification testing, which is where we bring all of the hardware together. In the process of this replanning, we have extended that time to 15 months. So, we have allowed a 4-month contingency over previous plans to accommodate any of the normal problems that may be encountered.

Mr. VOLKMER. Will that also mean additional funding is necessary?

Dr. LUCAS. Yes, sir, that is part of the schedule and cost contingency.

Mr. VOLKMER. Is that already included in what we have scheduled?

Dr. LUCAS. It is included in the estimated range I gave earlier.

Mr. VOLKMER. To get back to Perkin-Elmer a little bit, was there any problem with them in their failing to anticipate the necessary test equipment or jigs, et cetera, as they progressed in production of the mirror?

Dr. LUCAS. Yes, sir, Mr. Chairman. As it turned out, when they began the very critical assembly of the mirror, they didn't have all the test and assembly equipment that they needed. I think it was a matter of running into a more critical problem than they anticipated, and they did have to supply additional equipment. That is a part of the increase in cost.

Mr. VOLKMER. Did NASA have to undertake to pay for that additional equipment, et cetera? Wasn't that anticipated by Perkin-Elmer?

Dr. LUCAS. Yes, sir. It is not fee bearing, but it is a cost we have to pay.

Mr. VOLKMER. Do you have anything to say, in retrospect, looking back on the incentive award given to Perkin-Elmer?

Dr. LUCAS. No, sir. Perkin-Elmer has not been paid any incentive award in the last 18 months. If you look over the whole program up through the last evaluation, Perkin-Elmer had earned on the order of 52 percent of the award fee that was available during that time. If you consider the cost that they had incurred up to that period of time, the amount of award and base fee earned is about a 3-percent effective fee.

The award fee is usually done on the basis of 6-month schedules. We set up milestones, and on the basis of meeting those milestones, we determine or assess the amount of award fee that the contractor has earned. During those 6-month periods, they earned what we judged to have been about 52 percent of the award fee.

Mr. VOLKMER. At the present time, as I understand it, you have project people from Marshall at Perkin-Elmer. Is that correct?

Dr. LUCAS. Yes, sir. Jerry Richardson, our manager for the optical telescope assembly project, and about 18 or 20 people are in residence at Perkin-Elmer. They are in day-to-day contact with what is going on.

Mr. VOLKMER. This, of course, is beyond what is usually done?

Dr. LUCAS. We normally do not have a resident office of that size.

Mr. VOLKMER. This will mean additional cost to the Government, also?

Dr. LUCAS. Yes, sir, but I don't know that it would be an increase to the total cost.

Mr. VOLKMER. No, not total, but there will be some additional cost, traveling and so forth?

Dr. LUCAS. Yes, the travel costs will be higher then normal.

Mr. VOLKMER. We are going to have to recess for 10 minutes and then we will be back. I have a few more questions.

[Recess.]

Mr. NELSON [presiding]. The meeting will resume. Good afternoon.

Mr. Volkmer will be back very shortly. I want to continue with the questioning, if I may, Dr. Lucas.

What are the major lessons that you have learned from the space telescope development experience that you now have?

Dr. LUCAS. I think we have learned the importance of clearly defining a program before we begin. I believe we did define this program in its overall concept before we began. Some of the problems that we have had have concerned technology that didn't support where we thought it did. We encountered technical difficulties that have caused most of our problems.

One of the things that would be helpful, if we had the prerogative of doing it, is that instead of making a cost estimate and a schedule estimate at the end of phase B, that we be given some grace period at the beginning of phase C—design and development—to define the program somewhat better and only then give the runout cost and schedule.

Mr. NELSON. How does Marshall fulfill its responsibilities of oversight over the Goddard Space Flight Center space telescope activities?

Dr. LUCAS. The Marshall Space Flight Center program manager, Jim Odom, is the project manager over all elements of the project, including the Goddard Space Flight Center and the contractors. We divide program management into what we call levels. Level 1 is the headquarters program manager. Level 2 is the lead center or the managing center level, which has overall management responsibility for the hardware. Goddard would be level 3. These levels should not be confused with those levels of activity identified earlier for the space telescope hardware.

In the sense of the OTA and the support systems module, Marshall is both level 3 and level 2. The Goddard Center is responsive to the Marshall Center in the sense of a level 3 element of the program. This is in the development area. For operations it would be a different matter.

Mr. NELSON. We understand that the Marshall project office was initially organized functionally versus projectized by major subelement. Is that true and can you explain that?

Dr. LUCAS. The Marshall activity has never been projectized. The Marshall Center operates as a matrix organization where we have a project manager, and then we have a body of science and engineering people, the preponderance of our center, that constitutes our technical capability, and each of the projects draws upon that capability in the matrix fashion as they need to. As I believe you would define a projectized system, the project manager has under his direct management every aspect of the program. We do not now nor have we had that arrangement.

Mr. NELSON. Why was the functional organization used?

Dr. LUCAS. That is the system we use, sir. In each of our programs we have a project manager. Each project that is assigned to the Marshall Space Flight Center has a project manager and a project staff. The project manager draws upon the technical competence that we have in a matrix fashion to do the job and overview the program.

Mr. NELSON. Mr. Lujan?

Mr. LUJAN. I am still worried about all the dust and all that on the mirror. Does it go into launch in a clean room atmosphere, while it is in the shuttle?

Dr. LUCAS. I think the shuttle cargo bay is a tight structure; but it will not be a class 10,000 clean room that we normally will keep this telescope in throughout its history.

Mr. LUJAN. But you will have built up through that through launch while it is sitting there? Suppose the same thing happens as with the last launch, that it is sitting there for days on end? Is there protection of that there?

Dr. LUCAS. The mirror will not be exposed after it is assembled in the OTA and the support systems module to the extent it is in the clean room. It is a concern of ours to maintain cleanliness while we have it in the cargo bay of the shuttle awaiting launch. That is a concern that we have not completely resolved yet, but it will not be exposed in that environment to the extent that it would be in a clean room. That is from the standpoint of the geometry. The clean room would be cleaner but the geometry was ideal for contamination as far as the telescope was concerned at Perkin-Elmer during the processing of it.

Mr. LUJAN. One thing I didn't hear in all of this discussion either here or before this, which we normally hear, is if we had only had all of the money that we asked for in the very beginning we wouldn't have these problems. Does that apply to the space telescope, that if you had had more money you wouldn't have had all these problems?

Dr. LUCAS. No, sir. I don't believe we have made——

Mr. LUJAN. That is what I say. That is absent in these hearings, and it is very unusual and welcome, I suppose.

Dr. LUCAS. Your committee has authorized and the Appropriation Committee has appropriated what the agency has asked for in this regard. I don't think we have that complaint. The problem that we have encountered is that in the process of implementing the program, when the performance doesn't come up to your expectations, you are sometimes forced to use what you set aside every year for contingency for carrying on the routine or day-to-day performance. Therefore, you do not have that contingency to handle the unanticipated problems that come up.

Mr. LUJAN. The $45 million that you went up, did that come out of contingency or where did it come from?

Dr. LUCAS. I am talking about in the program itself, the contingency already in the program.

Mr. LUJAN. I realize that, but you say for 1983 you have $137.5 million.

Dr. LUCAS. We have already used the contingency, and that is the reason why we need the $45 million extra. The reason for that $45 million extra is that we have added program content in the sense that we have stretched out the schedule somewhat. There was some contingency in our 1983 budget which has now been used up.

Mr. LUJAN. It is a little complicated for me. I am just wondering where you are getting the money.

Dr. LUCAS. I am sorry, I must have misunderstood your question. I was speaking from the standpoint of the project itself. The agency has asked permission to reprogram some money in a letter from the Administrator to the chairman of the committee—I believe that has been sent to the committee already—indicating the sources of the funds to be reprogramed to cover the $45 million extra.

Mr. LUJAN. Does that mean there is $15 million too much within the physics and astronomy program; $2 million too much in spacelab payload and development; $3 million too much in space applications; or $26 million in space flight operations?

Dr. LUCAS. No, sir, I wouldn't reach the conclusion that there was too much there. I would say, given the problem that we had, an analysis was made and it was determined that this is where it should be spent because of the priority of this program over those others. It was just a priority judgment.

Mr. LUJAN. The reason I ask you that is we have trouble finding out exactly what things should be at what level. To be very honest with you, I suspect that almost everything has got some little extra there so that we can move it around.

I am trying to find out if these are the things we ought to look at when we are looking at budgets, that this is where we have a little money stashed away, a little slush there, so that when we need it somewhere else we can just reprogram.

You will get the reprograming authority, I am sure, unless someone is enamored of a particular program and they will raise Cain about that one, but in general you are going to get it. Is that a planned sort of thing, that we put a little here so that when we get in trouble somewhere else we can have a little slush fund, I guess, in a sense? If we have it, good; if we don't, it is all right, also.

Dr. LUCAS. I think Mr. Beggs might answer this question better for you.

Mr. LUJAN. Are any of these programs under Marshall?

Dr. LUCAS. I believe so; $12 million comes from the space telescope operation maintenance, and refurbishment. So, that is borrowing on the future somewhat. That is $12 million of the $45 million.

Mr. LUJAN. Thank you, Mr. Chairman.

Mr. VOLKMER. Dr. Lucas, earlier we talked a little bit about the problems at Perkin-Elmer and the fact that they didn't have the testing equipment ready. How is it that the project management staff at the time from Marshall wasn't familiar enough with the operations that they couldn't alert Perkin-Elmer to this?

Dr. LUCAS. It is not as if Perkin-Elmer had no equipment. They did not, as it turned out, have adequate equipment. Perkin-Elmer is the expert in this area. Perkin-Elmer is one of the top optical houses in the world. Marshall Space Flight Center isn't. We rely upon the contractor, and particularly one with the reputation of Perkin-Elmer.

Mr. VOLKMER. In other words, they had the expertise more so even than the people who were overseeing the management of it?

Dr. LUCAS. That is usually the case, sir. They have the expertise. I don't think there is any question that we have to rely upon a company that is manufacturing optics to have that expertise.

Mr. VOLKMER. On the fine guidance sensor and the fine guidance system and the problems with that, as I understand it, the present one is going to be used just for an engineering model?

Dr. LUCAS. The first fine guidance sensor will be used as an engineering model to test the system early. It will be shipped with the OTA, and it will later be refurbished as a flight unit. So, it is not as if it is going to be wasted. It will be used as an engineering model, and then it will be refurbished into flight configuration.

Mr. VOLKMER. But it won't be used in the initial telescope going up?

Dr. LUCAS. Probably not because we have a spare; therefore, it will be refurbished as a spare.

Mr. VOLKMER. Can you tell me later, when we give you all the questions, the additional cost as a result of that? In other words, it wasn't anticipated that it was to be used originally as an engineering model, was it?

Dr. LUCAS. We expect now to buy the same amount of hardware. I cannot give you offhand, but will submit for the record, the costs associated with any refurbishment that might be required.

[The information follows:]

We have maintained the capability to retrofit the Fine Guidance Sensor Engineering Model to flight configuration, therefore, the cost associated with the use of the first flight unit as an engineering model will be approximately $4.5 million.

Mr. VOLKMER. Did you originally anticipate that you were going to have two of them?

Dr. LUCAS. Sir, we planned on having four FGS, one of which was a spare. One of the problems in this program is we don't have enough spares.

Mr. VOLKMER. On the prisms, you discussed the additional costs on those. Who is going to be paying those additional costs?

Dr. LUCAS. The additional costs on the prisms?

Mr. VOLKMER. Yes. There are no additional costs for that?

Dr. LUCAS. We will pay for those prisms that we use, yes, sir. We will have to pay the cost on those.

Mr. VOLKMER. Were there additional development costs in that? Maybe I misunderstood the testimony. It says:

Careful selection and extensive testing of the Koesters' prisms on hand show that a satisfactory interferometer characteristic can be generated. This problem then became one of manufacturing adequate quantities of satisfactory Koesters' prisms. Additional studies are underway to resolve the cause of the manufacturing problems.

This is going to result in additional costs, then?

Dr. LUCAS. There will be some additional costs in selecting the amount of prisms, yes.

Mr. VOLKMER. In the manufacturing phase of it that won't cause any additional cost?

Dr. LUCAS. If the yield from the prisms is less than 100 percent, there will be extra cost.

Mr. VOLKMER. I started to get in on the spectrograph. I guess I could get into that with Dr. Hinners instead of you, or would you rather address that?

On the faint object spectrograph it says, "* * * it was found that both Digicon detectors have lost performance," that you are going to use existing spares before shipping the instrument to Lockheed Missiles & Space Co.

Dr. LUCAS. I believe Dr. Hinners will cover that.

Mr. VOLKMER. I will address any questions on those instrumentations to Dr. Hinners.

Because we don't have sufficient time I will have several questions sent to you in writing. I would appreciate you sending the answers back so we can have them be a part of the record. We will hold the record open until we can get those.

Dr. LUCAS. We will be happy to do so, Mr. Chairman.

Mr. VOLKMER. Let me ask you one other quick question. Again, this may be beyond your area and you may not want to answer, but in reviewing the whole space telescope operation, one sees that we not only have two associate contractors but we also have basically two, Goddard and Marshall, as far as overseeing the management, making sure everything is taking place. We don't have one specifically.

Do you wish to comment on that?

Dr. LUCAS. I have commented on the fact that we have two contractors, with Marshall responsible for both of those. We do have two centers, but Marshall is responsible to headquarters for the entire project and Goddard is responsible for their activity, but through Marshall.

One can argue whether that is a good system or not. I don't believe that there have been significant problems generated because of that relationship.

Mr. VOLKMER. In other words, the relationship between yourself and Goddard, as far as those parts of Goddard, has not created any of the problems that we are seeing in the delays?

Dr. LUCAS. I don't believe so, sir.

Mr. VOLKMER. Thank you very much.

Dr. LUCAS. Thank you, sir.

Mr. VOLKMER. We will now have Riccardo Giacconi testify. We had planned to have Dr. Hinners, but Dr. Giacconi has to leave. We will go ahead with him first. I want to thank Dr. Hinners for doing that.

Dr. Giacconi, you have a prepared statement. That statement will be made a part of the record. You may either review the statement or summarize, however you see fit.

STATEMENT OF DR. RICCARDO GIACCONI, DIRECTOR, SPACE TELESCOPE SCIENCE INSTITUTE

Dr. GIACCONI. Mr. Chairman, I will try to simply summarize the statement I have already made.

It is unfortunate that my testimony comes before Dr. Hinners' because it would have been a reasonable sequence, from the hardware development phase to the mission and operation phase and finally to science utilization. However, I think I can describe the role and the function of the Space Telescope Science Institute, which I direct now, and describe the status of our operations.

First of all, I would like to reemphasize the importance of this program to astronomy. You have heard lots of testimony. I would like to summarize it in my own way.

After 30 years of effort we still don't know some of the fundamental parameters which would describe the universe as we understand it today. In particular, we don't understand how long it has been around. We don't understand the lifetime of the universe, and this is tied in with the measurement of distance scale.

We started 30 years ago with the best effort, the best astronomers with the best instruments that we had, including Palomar. Still, we don't know this number to within a factor of two. It is a statement about ST capabilities that we believe that within weeks we will have the distance scale measured to within 10 percent and, therefore, the age of the universe to 10 percent.

On a completely different subject, it is still a fact that while we have studied our own solar system, we don't know about the existence of any other, because we don't know about the existence of any planetary system about any star except our own Sun. We believe that that problem will be solved in the first few years of operation of ST by carefully examining many of the nearby stars in an attempt to detect planetary systems.

The impact on all of astronomy of ST observation will be very great. It will bring additional requirements and additional needs for observation from the ground and from space in different wavelength regions. I believe that one of the major impacts will be to place all the problems we currently have in a somewhat new light.

There is no question that this instrument will have an impact which transcends the national scientific community and, in fact, the scientific community as a whole. Very early on NASA understood this point and decided to depart from its traditional way of running this program and to create an independent institute run by astronomers that would determine the observational program, that would determine what science that would be done with ST, and finally would disseminate this observation both to other scientists and to the public at large.

This was placed in more precise context by the Hornig committee, a committee of the National Academy of Sciences, chaired by Professor Hornig, which foresaw an independent institute which would have a significant role both in the development of the ST and in the operation phase of ST.

As it turned out, delays in the realization of this institute resulted in a somewhat diminished role of the institute with respect to the development phase, although the current delay gives us an opportunity to help somewhat more in that phase.

As a result of a competitive procurement, AURA, the Association of Universities for Research in Astronomy, which operates Kitt Peak and other ground-based observatories, was selected as the management institution for the Space Telescope Science Institute. The site selected was the John Hopkins campus in Baltimore. An additional selection determined the director and the deputy director.

I would like briefly to outline what the specific responsibilities of the institute are, particularly during the development phase, because they are quite substantial and they are often not understood.

The first duty we have, of course, is to develop a building, a facility itself. This has been accomplished. We have an opening ceremony tomorrow, to which we will be host to 350 scientists from all over the world and some 700 other guests.

The recruitment of the staff has been one of the primary concerns during the last 1½ years. It has been recommended by the National Academy and understood by all concerned that in order to properly operate this facility we need an institution which will attract scientists of the first rank.

The selection and the recruitment of the scientists has been a painstaking and careful process which has resulted in the hiring of some 33 astronomers coming from 22 different institutions.

The search process itself was carried out by an external search committee, chaired by Prof. Jerry O. Striker of Princeton and manned by some of the best astronomers in the world. The effectiveness of this committee can be understood when we find that we are able to attract people from some of the major academic institutions in the country, such as MIT, Princeton, CalTech and others.

The staff has already proven its competence and its particular ability in several areas, which I will outline later on.

The third item which we need to prepare before launch, and which is essential prior to launch, is to create a new catalog of stars. In order to point the ST, the fine guidance sensor must acquire guide stars, whose position must be very precisely known.

Since the field of view which the fine guidance system can explore is quite small, we must be sure that we can find a pair of guide stars in each particular direction in the sky in which we want to look.

In order to be sure that we have stars, we must know the position of very faint stars. Currently there doesn't exist any catalog which goes as faint as we need. The catalogs presently stop at a measure which is called the eighth magnitude. We need to have a new catalog of the sky to 15th magnitude. That will be a catalog of 10 million new stars.

This implies having a new sky survey made by Palomar Mountain, which has been accomplished—consistly of 1,725 plates—and other sky surveys that can reach the Southern Hemisphere from the telescope at Cerro Tololo. It implies scanning these plates with PDS machines and then providing the software, which can deduce the position of stars with a very high angular precision of 0.3 arc seconds.

I have gone in some detail in this, simply to point out that it is a massive job, an important job, a job which attempts to create a catalog in sort of series production with astrometric accuracy, something which has not been done previously.

Some 20 percent of our staff currently is involved in that kind of activity. The activity is proceeding extremely well in that they are essentially 80-percent complete as far as gattering the data, and we are proceeding well with respect to the development of software and the measurements themselves.

The second item for which we are responsible is scientific data analysis. When the data are transmitted to us from the Goddard receiving station as received from the telescope a first-cut data reduction will be done in which the characteristic of the instruments will be removed from the data.

Beyond that, it becomes what is really the proper area for the scientists, the theorists, the astronomer; namely, the interpretation of the information which has been received. This is generally described as a scientific data analysis system, a complex system of software and computers which is required to do interactive image analysis. We are responsible for the development of that system.

The third item is the science and operation ground system, for which we are not directly responsible. The contract was let to TRW Corp. This is a system of computers and software which is acquired for mission planning and operation, for pipeline data analysis and for calibration purposes. We ultimately are the users of this system. This system will be delivered to us as Government-furnished equipment, and we will then have to operate it after launch.

We have found in considering this system that although the requirements and specifications were very carefully laid out, there is, as usual, a certain gap between laying down the specific requirements and then realizing them in practice.

The scientists who will be operating this system have become very deeply involved in furnishing technical opinions and support to the development of this program. We have done this jointly with NASA, but we have found that we have had to assume a greater and greater role in this particular development item and in particular with one item, which is mission planning and operation, which is critical for flight.

The next item is that in order for us to operate the ST observatory we must become totally familiar with each of the instruments aboard. In order to achieve this expertise we have two scientists assigned for each of the instruments on board.

These scientists were members of the instrument development teams or are now. They are deeply involved in the development of the instruments, as well as their calibration and assessment. They find that they are being asked to provide considerable support to this instrument development.

Finally, during the operational phase is where the more clearly understood responsibilities are; namely, that we have to prepare to go out with solicitation for guest observers and researchers, to prepare procedures for a selection of observations, to prepare procedures for the dissemination of the data and services of that kind.

I would say that the current state of the institute is that we are essentially on schedule all across the board. There have been problems of cost increases, and the cost increases have essentially come in the areas where we have been asked to provide more support than was originally anticipated; in particular in the area of supporting the TRW contract, for SOGS, in software development, items which in a system as complex as this have been left out—careful examination shows that they should be in place in order for us to do the analysis—additional responsibility for the instrument scientists, and finally, a responsibility in a system study activity, which we believe to be absolutely essentially essential to insure that ST once flown will do what is intended.

By that I mean—if you will permit me in a less than formal parlance—we take our scientists and, like ferrets, we drop them down the hole and we find out if they come out of the other side. If they don't, then we try to find what the stoppages are and to point them out to various elements of the system so that proper corrective action can be taken.

I will conclude my remarks by making some comments with respect to some of the management questions which have been raised.

In my testimony you will find that I have expressed the opinion that there are no major technical unknowns. I think that maybe I should qualify that by saying that I am a physicist by trade and training and I am an astronomer by profession. I consider there not to be major technical problems if we are not required to find new laws of nature in order to carry out the project. Certainly as compared to nuclear fusion this is not physically or fundamentally challenging in nature.

On the other hand, there are very great difficulties in technology development. I think one of the major difficulties in fact is the fact that the system is so complex. We are finding that from our point of view, which is by definition a science integration point of view, we must make sure that all the elements of the program play together so that we can achieve the scientific observation we want. It is in this area the scientists can provide support.

I think substantial changes have been made in management which should favor this scientific involvement. There has been a feeling that there has been insufficient or not sufficiently in-depth scientific involvement in some facets of this program.

I think a substantial step in remedying that problem has been the creation of a committee reporting to headquarters, which will include the project scientists from Marshall, the project scientists from Goddard, members of the institute staff and members of the IDT teams.

Looking forward, I see no major problem. I am somewhat concerned in that I feel that in the current problems with development, operations needs tends to always be deferred. Preparation for the ground support system for a system as complex as ST are long and time-consuming and very difficult. I feel that funding through 1984 for that type of effort is essential if we want to assure success for flight in 1985.

Thank you.

[The prepared statement, plus answer to questions asked of Dr. Giacconi follows:]

Testimony
by
Riccardo Giacconi, Director
Space Telescope Science Institute
Subcommittee on Space Science and Applications
U.S. House of Representatives
14 June 1983

The realization of a long-lived (15-20 year), large aperture (2.4 meter) Space Telescope, launched and serviced by the Space Shuttle, and operated as an astronomical observatory for the world-wide astronomical and astrophysics community is almost within our grasp.

For many years now, NASA, in response to the urgings of the scientific community, has studied, planned, and is now building the optical telescope assembly, spacecraft, scientific instruments, ground system, and science institute which will eventually form the earth orbiting Space Telescope and its Baltimore-based scientific observatory/control center, the Space Telescope Science Institute.

The telescope, with its unique perspective of the skies, above the polluted, distorting, and frequently overcast atmosphere of the earth will permit the imaging of almost the entire range of astronomical bodies with 10 times the angular detail achievable with ground based telescopes. The Space Telescope will be able to detect sources 50 times fainter than those at the limits of the largest ground based telescope and so provides the unique opportunity to view objects deeper in space than man has seen before, in light emitted when the universe was only a small fraction of its present age. The absence of atmospheric absorption in the ultraviolet and infrared wavelengths will also enable the telescope to extend its observations into these spectral regimes, allowing both hotter and cooler astronomical bodies to be studied. These combined properties of high spatial resolution, sensitivity and wide spectral coverage promise to make the Space Telescope the most powerful and exciting astronomical tool of the decade and allow its observers to address such basic questions as the origin, evolution and ultimate fate of stars, galaxies and clusters, and of the universe itself.

From an early stage in the ST program, NASA recognized the importance of providing a research institute to operate the space borne telescope in a manner which would maximize the scientific return and so realize the full scientific potential of this unique facility. In consultation with a committee of world renowned astronomers and astrophysicists assembled under the auspices of the National Academy of Sciences, and chaired by Professor Donald F. Hornig, NASA determined that the scientific observations of the ST should be selected, planned and scheduled, and the data collected, reduced, and disseminated by a Space Telescope Science Institute. This institute would furthermore be independent of NASA in an intellectual, if not financial, sense and would service the scientific community in a manner analogous to the operations of the ground-based national astronomical facilities (Kitt Peak Observatory, Cerro Tololo, V.L.A., etc.). The Association of Universities for Research in Astronomy, Inc. (AURA), which already operates several of these major ground-based facilities for the National Science Foundation, won the NASA competition to develop and operate the Space Telescope Science Institute, which is located at the Homewood Campus of the Johns Hopkins University in Baltimore.

During the operational phase after launch, the Space Telescope Science Institute's charge follows the Hornig Committee recommendations. It has responsibility for selecting and supporting ST observers and archival researchers; planning, scheduling and conducting their observations; receiving, reducing, analysing and distributing their data; monitoring and assessing the performance of the scientific instruments; making recommendations for new instruments or modifications to the ST; and for the promotion of international participation and the maximization of scientific returns from the Space Telescope.

Late implementation of the Hornig Committee recommendations initially precluded the Institute from playing its intended major role in the development phase. Instead, its tasks were limited to the acquisition of staff and facilities and a few specialized technical tasks.

During the development phase of the ST program, the Space Telescope Science Institute must develop the Guide Star Selection System (GSSS); a complex array of high precision measuring engines; associated computers and peripherals, comprehensive star catalogs and astronomical data archives, and software for astrometric and operational computations, which will be used daily in the identification and determination of the Guide Star pairs required to support every new Space Telescope observation.

The Institute must develop the Science Data Analysis Software (SDAS); computer software to be used by the ST observers and researchers in the reduction and analysis of their observations. It must also develop the software to determine and update the calibration parameters to be applied to the scientific data received from the ST after launch. All this software will eventually run on the Science Operations Ground System (SOGS) which is currently being developed by TRW, under contract to NASA (Goddard Space Flight Center).

Institute scientists have provided and must continue to provide a significant amount of technical support/direction to both NASA and TRW to assure that the SOGS system will have adequate planning, scheduling operations, and data manipulation/archiving capabilities at the time of ST launch. They must also develop the people and computer procedures which will be used to run the SOGS system and to conduct the ST observations. ST ScI staff must develop the detailed knowledge and understanding of the optical telescope assembly, fine guidance sensors, and scientific instruments which will enable them to monitor and assess their performance during the operational era of the ST program. Finally, they must develop the criteria, ground rules, support materials, and procedures for the observer and researcher solicitations, and must begin the process of educating the consumer, i.e., the world-wide astronomical community in these matters, in preparation for the first call for proposals for use of the Space Telescope.

This comprehensive array of pre-launch and post-launch responsibilities demands an indepth knowledge and understanding of astronomy, the astronomical community, space observatory operations, ground-based observatory observations, computing, and scientific instrument development which is only realizable with a staff of top rank scientists. In order to attract and retain a scientific staff of this caliber, the Space Telescope Science Institute must in turn establish itself as a first rank research institution.

Despite its late start, due to NASA funding constraints, the Space Telescope Science Institute has made remarkable progress. It has supported The Johns Hopkins University in the construction of the ten million dollar Space Telescope Institute Facility (two million of which was provided as a gift by JHU, with funding support by the State of Maryland). The facility, which will be formally opened tomorrow, has been constructed on an accelerated schedule by the "fast track" method with only a 10 percent overrun on its original budget and only two months behind on its original completion date. A remarkable feat in present day conditions!

All the key scientific positions have now been filled. At this time 33 scientists from 22 institutions, have been recruited by the Institute, including nine scientists and support personnel from the Europen Space Agency, which is collaborating with NASA in the ST Program. This recruitment process has been a time consuming and painstaking one, since it is the key to the success of the Space Telescope Science Institute. Without the appropriatate mixture of observational, instrumental and astronomical expertise, the Institute cannot achieve its objectives. The business, financial, programmatic infrastructure, which is needed to operate a facility of this size and type, is now almost entirely in place.

The progress of the Space Telescope Science Institute in its major technical developments has been equally successful. The Guide Star Selection System is fully designed, most of the hardware associated with the system is now at the Institute and is about to be upgraded to its full operational specifications. A significant fraction of the astronomical data sets have already been assembled for use with the system and the capability now exists to start developing the "coarse scan catalog" from which guide star availability will be deduced. The software for the GSSS is also fully designed and is currently under development, with an expected completion late of mid 1984. This development has grown little in cost and schedule since its conceptual design was accepted by NASA almost two years ago.

In the case of the SDAS, progress is equally good. The preliminary design is complete, and the final design and development, which is to be accomplished in a series of five "builds" is well underway, with one Build Design Review already successfully accomplished and another scheduled for July this year. Once more the cost/schedules growth in this program since the detailed negotiations of January 1981 have been small, despite the mismatch between the SDAS and SOGS development schedules and the resulting need for the development of a "SOGS test bed" at the ST ScI.

With the delay in launch, it has become possible for the ST ScI to assume an expanded role in development phase activities which is in far closer accord with the original Hornig Committee recommendations. This has allowed increased Institute involvement in activities such as SOGS development and system studies.

The ST ScI staff have proved their worth in the support of the SOGS development and are increasingly in demand to provide technical expertise to TRW and NASA personnel. This has been an area of cost/staff growth at the ST ScI, not because of any lack of Institute performance, but as a result of increased scope of work. A similar situation exists in the ST ScI participation in

Instrument Calibration/test activities and in system wide ST studies. The proven expertise of ST ScI scientists has resulted in increased demand, increased scope and increased costs.

The fact that the ST ScI (and the ST Program) has grown in the areas of SOGS support is scarcely surprising. It was the inadequacy of funding and early delays on the ST Program that led NASA to postpone the establishment of the ST ScI until after the issuance of the request for proposals for the SOGS system, and the award of the SOGS contract to TRW. Such a mismatch in schedules was bound to result in some difficulties when the actual users of the SOGS system (the ST ScI) defined their operational procedures and reviewed the adequacy of the system being supplied to them by NASA. There are no significant technological problems at hand in the SOGS development activities, merely questions of software design which must be solved by TRW and the ST ScI before launch and which will require adequate funding in FY '83, '84 and '85 for their solution. Lack of this support would, almost certainly, result in launch delays for the ST.

Similarly, the growth in the ST ScI role in ST system studies is hardly a surprise. Most major ground-based and spaceborne scientific developments have an individual or group which provides the scientific and technical leadership and coordination. This leadership was, to a large part, missing in the ST Program, due to the inadequacy of the support provided by NASA to the Marshall Space Flight Center Project scientist, Dr. O'Dell, and the ST Science Working Group which he chairs. The situation was further aggravated by the absence of a prime contractor for the ST development and by the multiplicity of contractors and interfaces in the Program. Without strong leadership and with such complex interfaces, system wide oversights, for example, the provision of the capability of the ST to tract comets, and other moving targets, were bound to occur, and they did. Once more, I do not believe that there are overwhelming technological problems with the elements of the ST

Program (including the currently contaminated primary mirror and the fine guidance sensors, both of which are under development by the Perkin Elmer Corporation), there is just the need to establish the appropriate scientific/technical leadership and the system-wide management structures to bring the elements of the ST Program together into an appropriately functioning whole.

How can this be achieved? In reviewing the current situation, NASA has already made significant progress in strengthening its management in certain critical areas, for example, at Perkin Elmer (to help with the mirror and FGS developments), at MSFC to strengthen the overall management of the Program and at NASA Headquarters to provide stronger inter-center control and coordination. It is also establishing a stronger scientific leadership structure, and has formed a science performance evaluation group of five scientists drawn from the IDT's, the ST ScI, GSFC and MSFC. This group will need unlimited access to information at all levels of the Project with appropriate technical support in order to function effectively. NASA has also identified additional support at the ST ScI and elsewhere for the conduct of the system-wide study activities.

In summary, the Space Telescope Program still promises to be the most exciting astronomical achievement of the decade, and despite the schedule delays and cost increases, should prove a prudent, important, and exciting investment in U.S. science. The problems faced today are problems of management and inappropriately phased funds, which can be alleviated with appropriate management restructuring, scientific leadership and funding provisions. In the case of the Space Telescope Science Institute, excellent progress has been made in the facility, the staffing, the major hardware and software developments and in providing an integrating function for science requirements from the users point of view.

A major element of risk lies in the SOGS development, where the unavailability of adequate funding in the FY '83 and FY '84 period could result in unworkable schedules for the completion of the system and in the unavailability of an operational ground system in mid FY '86 to support the ST launch. In this and other areas of technical problems, I believe the key lies in careful, informed evaluation of trade-offs to allow the necessary scientific performance without unnecessary over specifications.

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8 July 1983

The Honorable
Harold L. Volkmer
Chairman, Subcommittee on
Space Science & Applications
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Re Space Telescope Program

Dear Chairman Volkmer,

Following are answers to the questions posed in your letter of June 27, 1983.

1(a) In order to obtain guidance with very high precision, it is necessary to image the sky through a high angular resolution mirror. On Space Telescope, the primary optical system is used both for imaging and for guidance. This implies that a very small field of view is available for each of the fine guidance sensors, actually about 1/50 of a square degree or about one part in two million of the sky.

Existing catalogs only go to stars as faint as 9th magnitude, and there are only about 250,000 cataloged stars brighter than that in the sky, i.e.in the SAO catalog. If these stars were uniformly distributed over the sky, we could expect to find guide stars for only about one field in 64; and the actual situation is worse because disproportunately few of these stars lie near the galactic pole. The requirement to find a star in each of two fine guidance sensors could not be met if we were limited to the SAO catalog.

By extending a catalog to much fainter limits, ie. 15th magnitude, we will obtain positions for about 20 million stars with the consequent certainty of having guide star pairs for about 95% of the fields.

(b) The creation of this catalog entails obtaining plate surveys in the northern and southern hemispheres, scanning of the plates with the microdensitometers (Perkin-Elmer PDS machines), and making astrometric analyses of the data. It also entails photometric observations to establish an accurate photographic reference scale for stellar brightnesses.

(c) The activities are on schedule. The new plate surveys are essentially complete south of declination -20^{o} and about 50% complete north of that. The PDS machines have been installed. The prototype software has been developed and tested, and production software will become available in the second half of this year. The photometric survey is 80% complete in the southern hemisphere, 50% in the northern hemisphere.

The catalog will be completed at launch.

(d) The major spin off of this work is the acquisition of an accurate star catalog going to fainter magnitudes than any previous one. It will become a standard reference in the field of positional astronomy.

(2) The problems in the Fine Guidance System were understood prior to my joining the ST program in September 1981. In the first Science Working Group meeting I attended in October 1981 in Baltimore, I felt that the problems which had been perceived were not receiving sufficient Project attention for a satisfactory solution.

My reaction was that the complexity of the Fine Guidance Systems was such that they should have received high level scientific attention and not be left entirely in the hands of the Perkin Elmer Corporation.

The situation has improved somewhat in the past several months due to increased recognition of potential design flaws by the scientists involved in the program. The study initiated under the leadership of Professor William Fastie by The Johns Hopkins University and Applied Physics Lab directed toward an alternate system will also be extremely beneficial in increasing our understanding of the present system.

The science returns from the ST mission are in large part dependent on the proper operation of the Fine Guidance System.

(3) There has been an effective step taken in insuring science inputs into the program by the recent creation of the Space Telescope Observatory Performance Assessment Team (STOPAT) under the chairmanship of Dr. Robert Bless. This team, which includes the Project Scientist at MSFC, the Project Scientists for Operations at GSFC, the Deputy Director of ST ScI and the Program Scientist from NASA Headquarters will have direct access to Headquarters, NASA.

I believe that this can become an effective mechanism to insure high level science inputs into the program.

(4) The Space Telescope Science Institute has been extremely

successful in recruiting highly qualified personnel, in establishing a facility and in carrying out all of the programatic tasks assigned to us. The areas of responsibility of the Institute have grown with time to become closely alligned to the original recommendations of the Hornig Committee of the National Academy of Sciences. The Institute is now deeply involved not only in the preparation for mission operations, but also in the development of Space Telescope.

Not all the tools that the ST ScI will operate after launch are being provided by us. The observatory itself is, of course, being developed outside of our control. But even in the area of Science and Operations Ground Support Systems (SOGS) which we will have to directly operate, the development is occurring elsewhere (at TRW) under contract to NASA.

There have been continued difficulties in insuring that the hardware and software being developed there will meet our requirements. Although some steps have been taken by GSFC to insure better exchange of the technical information between our people and the TRW developers and better feedback mechanisms, it is not yet clear that these steps will be sufficient to insure success. SOGS remains an item of great concern to me.

I hope I have been able to answer your committee's questions to their satisfaction. If I can be of any further help, please let me know.

Sincerely,

Riccardo Giacconi
Director

/mf

Mr. VOLKMER. The gentleman from New Mexico?

Mr. LUJAN. I have a couple of questions, Dr. Giacconi. Is the Space Telescope Science Institute a division of the National Academy of Science?

Dr. GIACCONI. No, it is not. You should think of it as a wholly owned subsidiary of a consortium of universities called AURA, the Association of Universities for Research in Astronomy, which is a not-for-profit organization of 17 constituent universities with a board. They exercise management oversight through several committees, the board of directors, and a Space Telescope Institute Council, which provides oversight to insure that we are following general policy laid down by NASA and by the constituent universities.

Mr. LUJAN. Funded by NASA?

Dr. GIACCONI. It is funded entirely by NASA. We are the executive arm, if you wish, of this association.

Mr. LUJAN. Do you feel that there is enough input on the part of the institute as far as NASA is concerned during the developmental program, so that you have a good handle on it when, as a matter of fact, it is launched and out there?

Dr. GIACCONI. First of all, I would say the answer is yes. The difficulty is that the institute was formed late. It had to run very hard to catch up to this moving train. The definition of its tasks and the mechanism for this interaction was not quite clearly in place at the beginning. They have now been established, and have been established in an extremely satisfactory way. In fact, you will find institute representatives on every major study group, committee, review team, and so forth.

I would say the answer is yes, it has been developed.

Mr. LUJAN. Why I ask that question, I wonder if when any changes are made, that there is sufficient discussion with you who are going to be the interpretors of the data; that if a change needs to be made, something either taken out or put in, what that means in terms of what you will need for implementation.

Dr. GIACCONI. I would say that the institute is capable of having itself heard.

Mr. LUJAN. And have been?

Dr. GIACCONI. Yes.

Mr. LUJAN. How about with TRW, who is doing the software and the computers and all of that which will deliver the data to you for interpretation? Is that a pretty good working relationship?

Dr. GIACCONI. We have been involved as part of the review committees on some of the major reviews which had to assess the suitability of the TRW effort with respect to what is required. We have provided our input in very great detail.

Our communication with TRW on a technical base has been facilitated by NASA in that we have very frequently now technical communications with them. We have also developed, since we have found areas of weakness, a plan for recovery jointly with NASA. By NASA I mainly mean Goddard, which is our direct managing center. I believe we have, at least in principle, agreement, although this is one of the very areas where the funds may be missing in 1984 to permit us to do the job.

Mr. LUJAN. Is it pretty easy to make changes? If you make a recommendation of some software, we will say, or some computer or some machine that you need—and I assume that it is building, also, is that correct; maybe you need different computers in different rooms or whatever—is it pretty easy to translate that, what your idea is, into an actual change for TRW? I suppose it has to go to NASA, since NASA has——

Dr. GIACCONI. First of all, we do not have programmatic or technical direction on TRW. We are not permitted directly to order them or to direct their work.

I have found that typically a program which is in some financial difficulty is very resistant to change, whether it be good or bad. So, from my point of view a change means to persuade people that something is essential for the program and should be done.

Mr. LUJAN. Have you run across things like that?

Dr. GIACCONI. Yes.

Mr. LUJAN. Have they been done?

Dr. GIACCONI. Yes; they have been done. It takes about 9 months—it is just like having a baby—from conception to delivery.

Mr. LUJAN. Mr. Chairman, I need to leave.

Thank you, Dr. Giacconi.

Mr. VOLKMER. Mr. Chandler?

Mr. CHANDLER. Thank you, Mr. Chairman.

Dr. Giacconi, to follow up a little bit on the gentleman's questioning, I am not terribly familiar with the process of building something like this, but I do know that the Boeing Co., when they build an airplane, that their engineers will design it, then they will build a prototype and test that, and then they will build their first one and go out and fly it, and after they have worked the bugs out of that, or most of them, they will go build the series. Maybe it is the new 5-7 or 6-7.

From the testimony I have heard this afternoon from Dr. Lucas, and somewhat from you—of course, we are not going to build a prototype and then we are not going to build a test and then build a third one to put it in space, obviously—I am getting the impression that there has been somewhat of a design-as-you-go process at work.

Is that a mistaken impression or would you say that that is somewhat correct?

Dr. GIACCONI. I don't believe so, although perhaps I am not the most qualified to comment. Until September 1981, I was doing something else, and I became involved in the program since then.

As far as I know, the general, overall philosophy and design of the development item itself, the ST itself, as well as the operation, has not changed. So, there has been a blueprint which has been followed.

I think you realize that we didn't build the prototype and then Mount Palomar. We built a small Palomar, perhaps, and then a big Palomar. In a sense, OAO or Copernicus could have been that first prototype test.

I think, however, the jump is substantial enough and the complexity of the instrumentation is sufficient that ST constitutes a first in many ways. This is the first time we used a shuttle to put up a permanent observatory in space. It is the first time that this observatory is totally dependent on TDRSS, the communication system, to transmit the data to the ground. Also, it is the first time we tried a sociological experiment, at least for NASA, in having an institute run the science operation.

So, there are many first things. I think part of the importance of space telescope is that it would be the first observatory of a series which is being planned as part of the national program in astrophysics. So, it is very important that we make this one work.

Mr. CHANDLER. This is a question I think that I would like to have Dr. Lucas respond to in writing, if he would, that occurs to me, and Dr. Hinners as well. Perhaps you can comment on this.

If you had your druthers and you could do it all over again, would you have as many cooks in the kitchen on this deal? I know one of the scientists at the University of Washington and have talked to him. It has occurred to me that while he is an eminently qualified individual and can talk your ear off about this project and has brought me to be one who is very excited about it, at the same time it occurs to me that he is just one of dozens out there who are having something to say about this.

Having been one who has managed projects, although nothing anywhere near as technical as this, I can say that whenever I could get a client to let me have very, very few people to deal with it was always a heck of a lot better than when I had a whole bunch of them.

I would be interested in all of your responses to that.

Dr. GIACCONI. I would say certainly there is some element of validity in what you are saying. From our point of view—and please understand that this is only one point of view—it is very difficult for us to deal with the many interfaces which are in the program and the several centers and so forth.

In addition, by having created this institute late we were forced to play catchup football rather than becoming involved early on.

I would say one lesson that I learned from this is that to the extent that the creation of such managing entities as the Space Telescope Science Institute is considered to be a success, which I believe it is, then an earlier implementation would be most beneficial. That is something that I think ought to be kept in mind for the future.

Mr. CHANDLER. I thank you for that answer. I think that is a candid one, and I appreciate it.

Thank you, Mr. Chairman.

Mr. VOLKMER. Thank you.

Dr. Giacconi, on page 2 of your statement you say:

> This institute would, furthermore, be independent of NASA in an intellectual, if not financial, sense and would service the scientific community in a manner analogous to the operations of the ground-based national astronomical facilities (Kitt Peak Observatory . . . etc.).

What are you telling me there? Are you saying that the operation of the institute will be independent or you wanted it to be?

Dr. GIACCONI. I looked up the definition of independent, Mr. Chairman. In the English language, independence can mean many things. It can be independence as far as sentimental tie, financial means, and so forth. Certainly we are not independent in that sense because all of our funding comes from NASA.

When an independent institute was advocated and then built, one can ask what was meant by that. I think what is meant by that, at least in my opinion, is that what is required by us is independent judgment; not to look to others to establish our values.

Our values are science and scientific cooperation, international cooperation and excellence. As to that, we don't look to anybody for guidance. What I would expect is that if questions came up regarding what should be done with science, we will be able, using our committees and advisory bodies in the astronomy community, to come up with an independent judgment.

Mr. Volkmer. As far as determining use of the space telescope—in other words, what are we going to observe, what series are we going to do—you would anticipate you would be able to make those determinations, correct?

Dr. Giacconi. Yes, sir. On the first 2½ years, 30 percent of the time of the space telescope is dedicated to those scientific groups which have built the instruments, as a reward for their 11 and more years of painstaking service.

The 70 percent has to be allotted. In principle it is my responsibility to do that. Of course, in a statutory way I cannot do that without the advice of the time allocation committee, which is a committee of astronomers from all over the world, which will judge the proposed observations.

There is a small amount of time which will be directed as discretionary time, and this will be used both for necessary calibrations and things of that kind, to perhaps support innovative programs such that could be judged risky or could be judged not suitable for peer review; finally, for taking advantage of targets of opportunity, the finding of a new super nova or something which will require fast judgment. That is my job to do.

Other than that, the astronomical community, using its traditional method—that is, peer review—will determine what observations should be made.

Mr. Volkmer. In your statement you also said you are precluded from playing your intended major role in the development phase on the space telescope.

What intended role would you envision to have been the institute's in the development of the space telescope?

Dr. Giacconi. Starting from nearby, I would certainly say that an earlier involvement in the definition and the technical direction of the software development and computer development for the ground operations—that is, to develop the equipment that we will be using—would obviously have been extremely beneficial. I think it would have saved a lot of problems and a lot of money.

Mr. Volkmer. What are the problems with it as it exists now? TRW is doing the software, basically, with a contract with NASA, right?

Dr. Giacconi. That is right.

Mr. Volkmer. Yet, your people are having input into that, are they not?

Dr. Giacconi. That is right.

Mr. Volkmer. Well, what are the problems? Tell me what the problems are.

Dr. GIACCONI. The problems arise in going from the statement of the requirements to the interpretation and then the execution. Let me give you one example of something which in fact has been corrected and is okay now, but which we had to point out.

Mr. VOLKMER. Are we talking about the catalog?

Dr. GIACCONI. No. They have nothing to do with the catalog. Part of the science and operation ground system was to provide interactive imaging terminals. That is something that shows you an image and then you can operate on it, multiply, divide, et cetera.

Of course, this type of system has been developed to a high degree of refinement for scientific use, in particular by astronomers and by the astronomical community. They are not, as often used in application or in technological matters.

Therefore, TRW simply interpreted those requirements to be met by using a type of display which we would call dumb. By dumb we mean it didn't have a lot of memory or a lot of capacity.

We pointed that out early on, about January 1982, and it took a lot of trouble because it meant now replacing the contracts, changing the equipment and so forth, but actually was done. It was understood to be required and was done.

I think the problems come not from technical incompetence, but basically because the scientists who actually use these things ultimately must become very deeply involved in how these things are developed. Otherwise, they will always find later on they have to be corrected.

I think this is the thrust of the statements I have made.

Mr. VOLKMER. In other words, you would much prefer to have direct involvement in setting up the demands and requirements on the software?

Dr. GIACCONI. That is right.

Mr. VOLKMER. But you are able to overcome these problems?

Dr. GIACCONI. Yes, with substantial sympathy and cooperation and help from Goddard Space Flight Center, without which these fixes could not occur; but with a certain reluctance, of course, because we come in late and we cause a lot of trouble. From one point of view you can consider us the hero of the story and from the other just a pain.

Mr. VOLKMER. Again, as a person who is not an astronomer, one of the things is to make a new catalog for the stars, so the telescope can point to the known ones. Why can't we use the existing information?

Dr. GIACCONI. There are 10,000 stars of 8th magnitude in the sky. The sky is 40,000 square degrees, so there is 1 star every 4 square degrees.

Mr. VOLKMER. Those are all known, right?

Dr. GIACCONI. Those are all known. The field of view in which the fine guidance sensor can point is one-ninth of a square degree, so the chance that you can find a guide star in any given direction is one part in 36. If you only use stars that you know, you will be able to only use 5 percent of the sky.

If you want to make sure that you will get a pointing direction, a guide star, everywhere you want to in random directions in the sky, then you have to go to fainter and fainter stars because there are more and more of them.

So, if you get to 10 million stars, everywhere you point you will have enough stars that you can select an appropriate guide star pair.

Mr. VOLKMER. This will all be implemented within the new SOGS?

Dr. GIACCONI. No it is not part of SOGS, the GSSS, guide star selection system, is an institute responsibility.

Mr. VOLKMER. Let's go back to the very beginning of this whole space telescope. Could the telescope guidance system been designed originally to work with existing catalogs?

Dr. GIACCONI. No, I don't believe so.

Mr. VOLKMER. It would not work to the extent that you want to do so?

Dr. GIACCONI. That is right. We are trying to achieve very high pointing accuracy. This is determined essentially by the smallest slits that we have to put on an object; that is, the spectrometers have a width which is one-tenth of an arc second. We must point the telescope to that precision in an absolute sense in order to be able to make sure that we can put this slit or this spectrometer on the object that we want without a priori knowledge of it.

Mr. VOLKMER. Are we on schedule for the guide star?

Dr. GIACCONI. Yes. As I mentioned, we are on schedule on every item of the program in which we are involved. The science data analysis software is developed in a build approach. Pieces get done every time—we finished the first one. The second one is due for review in July. We are on time on that. We are on time on the guide stars.

We were about 2-months late in the construction of the building, which we did not construct. Johns Hopkins University has built it for us, with our help and involvement, and they were about 2-months late on a very fast track approach and 10-percent above on the cost, which I thought was a very good performance.

Mr. VOLKMER. Are you satisfied that there is adequate effective input from the science community into the space telescope development?

Dr. GIACCONI. As I mentioned, I had some concern about that. Some of that concern has been relieved by the creation of this new committee, chaired by Prof. Bob Bless, which reports to headquarters.

The advantage of that is it will contain the institute representative, it will contain representation from the project scientists at Marshall and project scientists at Goddard, as well as members of the instrument development teams, and can cut across the boundaries between the various NASA centers or even contractors or whatever.

So, it has, in fact, a great deal of access to problems. It can spot problems and can bring them to the appropriate level of attention so that it can be corrected. I think that was a very good step.

Mr. VOLKMER. You understand the problems that NASA and the contractors are facing in the completion of the telescope?

Dr. GIACCONI. As a bystander, as a spectator. An interested one, I would say, but as a spectator.

Mr. VOLKMER. Of course, everything hinges on the fine guidance system. Do you understand the problems that you are having with that?

Dr. GIACCONI. Yes; we do. Our job in that area is not to step in and do development that somebody else is doing. We have to understand it, though, because that particular fine guidance system will have to be used for astrometry as a scientific instrument.

Professor Fasté of Johns Hopkins University, joined by Prof. Jim Gunn of Princeton and Prof. Jim Westphal of CalTech, are undertaking a kind of systems analysis of the fine guidance sensor in order to then develop an alternate sensor.

We have one of our senior staff participating in that study as an observer, so that we can absorb and understand what the problems are in that area. We are satisfied that the appropriate steps are being taken.

Mr. VOLKMER. You are satisfied that you will be able to do the equivalent of being able to pinpoint the dime in Boston from Washington, D.C.?

Dr. GIACCONI. Yes; I certainly hope so. We have to.

Mr. VOLKMER. You are doing everything based on that?

Dr. GIACCONI. Yes; ST is not a very large telescope. It is only half Palomar. It has to be very accurate or else it will not carry out the promise that it has. So, we are interested in the maintenance of this characteristic, a concept that NASA certainly has embraced and has held firm through thick and thin.

Mr. VOLKMER. Do you have any problems with the Space Telescope Science Institute? Are there any problems arising that we should know about?

Dr. GIACCONI. The only problem we have is we have hired a very, very good scientific staff, as I endeavored to mention. Regarding the work, we have an ideal of service and research, which is the one under which the scientists have been hired. They understand that they are to give service to the community for half of their time and they will be allowed to do research, in competing with other scientists, for half of their time.

The workload and the desire to understand the nature of the system and to help in its development has been so severe that, in fact, research during the first year of the institute's operation was less than 10 percent of the time.

That situation cannot be sustained over a long period because these are very highly motivated scientists and they simply will not give up their research for years and years on end. My problem, as the director, is to make research opportunities available for them, to improve that situation. That I would consider one of the most significant problems.

Mr. VOLKMER. Getting back to the software design for SOGS development activities, you say:

> . . . merely questions of software design which must be solved by TRW and the ST ScI before launch and which will require adequate funding in fiscal years 1983, 1984 and 1985 for their solution. Lack of this support would, almost certainly, result in launch delays for the ST.

We have 1983 and we have done 1984, at least part of the way. Is the funding adequate there?

Dr. GIACCONI. Perhaps that question should be better directed to Dr. Hinners. All I can say is that the problems have been identified and the work which has to be done has been identified.

Remember, we at the institute are a level 4 in this chain of command, or lower, but we have certainly not been assured that we will have those funds, which are very modest compared to the numbers that I have been hearing today.

If those funds were not to be available, we could see a problem arising in getting ready for launch in 1986. That is all I meant.

Mr. VOLKMER. You also say:

> A major element of risk lies in the SOGS development, where the unavailability of adequate funding in the fiscal year 1983 and fiscal year 1984 period could result in unworkable schedules for the completion of the system and in the unavailability of an operational ground system . . . to support the ST launch.

Dr. GIACCONI. That is what I mean. The point is that the ground support system for a spacecraft of the complexity of ST is itself a complex job. Whereas in the past one could just start developing the ground support system when essentially all the development effort was over, here you have years of development.

Time is running. Even now Canndi is only 3 years away. I think it is a proper concern, that we can be ready for launch. We certainly have a path clear to us. I don't see any major problem in following that path, but funding constraints are a problem; that is, to the extent that we continue having development problems, then they tend to push away or tend to delay the mission operation activities.

All I am saying is that you can't afford to play that game too long.

Mr. VOLKMER. Thank you very much, Dr. Giacconi.

Dr. GIACCONI. Thank you, Mr. Chairman, for the courtesy in allowing me to testify.

Mr. VOLKMER. We will now have Dr. Noel W. Hinners, Director, Goddard Space Flight Center.

Dr. Hinners, your statement will be made a part of the record, also. You may either summarize or review the full statement, however you so desire.

STATEMENT OF DR. NOEL W. HINNERS, DIRECTOR, GODDARD SPACE FLIGHT CENTER

Dr. HINNERS. Thank you, Mr. Chairman. I appreciate the opportunity.

What I would like to do today, using some visuals, is to explain to you what Goddard's role is, what our relationship is to both the Marshall Space Flight Center [MSFC] and to the science institute, both of which you heard about before, and tell you where we are in the development of the Goddard responsibilities and what I see as the outcome.

Due to the late hour I will save my comments on Goddard management, and its relationship to Marshall and such funding for the end.

[Enclosure 1.]

The entire responsibility in the space telescope [ST] project, you might say at both ends starts, and stops with science, when the science detection of an object comes into the scientific instruments inside the space telescope. As you heard before, Marshall has overall project management responsibility and also for the OTA and the support system module development.

From the instruments, then, the data from the telescope will go through the antennas to the tracking and data relay satellite system (TDRSS); down to the White Sands ground station in New Mexico, where it will be transferred through domestic satellite to the Operations Control Center at the Goddard Space Flight Center [GSFC]; from there it will go to the Space Telescope Science Institute, which then turns out the final science products.

[Enclosure 2.]

The heart of the science system is in the detectors. You have heard before that our objective is to see out to the edges of the observable universe, about seven times greater distance than we can see from our current Earth-based observatories. The detectors—and that you will hear more about in terms of the instruments—are the guts of the instrument. Detectors are what we call these charged coupled devices, solid-state devices, which improve sensitivity by about a factor of 3,000 to 10,000 over the historical film that has been used in telescopes primarily on the ground. They also yield a significant increase over the television systems that are typically used in space now.

Those detectors have been at the heart of some of our development problems and are ones which we are now most concerned with.

[Enclosure 3.]

In terms of an increase in what we can see, both the telescope itself and these detectors are responsible for this increase of a factor of 10. Just to give you some feel, this is what you would see in a comparable Earth-based telescope photo. Here is what the space telescope itself will see.

This demonstrates a problem that Riccardo Giacconi touched on before, of being able to find very faint stars so that when you home in on small objects, you can have that star as a guide for the telescope.

Many of our detectors will home in on a field which has almost no stars in it. This happens to be a very rich field right through a core part of our own galaxy, but most areas you look at you see very few, just one or two of these very faint objects.

[Enclosure 4.]

We should remember that the ST also has near-in capability. The wide-field planetary camera is going to be able to see Jupiter somewhat as Voyager saw it as it approached and gave us these marvelous pictures of the planet.

With the wide-field camera system, we will be able to monitor the planets of the solar system on a continuous basis to do, you might say, the climatology of the planets for a period of decades.

[Enclosure 5.]

The Goddard responsibility is in the instruments. In a stripped off version of the telescope, the instruments fit in here. We have four axial instruments, as they are called, and one radial instrument, which fits in from the side.

There are three kinds of basic instruments: two cameras, one the wide-field planetary camera, with the principal investigator, Jim

Westphal, from CalTech; it is being built by JPL, complemented by the faint object camera supplied by the European Space Agency.

The wide-field planetary camera is in its final stages of acceptance testing and is expected to be shipped to Goddard in August of this year. The European faint object camera, which has had some setbacks in the past, now appears to be back on schedule and will be delivered to Goddard in October of this year. A little later I will get into what is going to happen when all these instruments come to Goddard.

The second class of instruments includes the spectrographs, which do not return pictures or images as you commonly think of them, but measure the spectra, which tells us about the elemental composition, the velocities of gases in space, the composition of the stars, how they are formed, how they are exploding in supernova, and how quasars and that type of object are formed.

We have two of those. One is a faint object spectrograph, which is designed to collect for a long time the light of very faint objects; the other is a high resolution spectrograph, which is designed to operate on brighter objects.

All of our instruments in that sense are complementary. We have faint object cameras and spectrographs and wide-field and high resolution cameras.

The high-speed photometer, the last class of instrument, is designed to look at the light output of stars at very fine time resolution. We know that stars vary in their brightness. By analyzing the brightness on a fine time scale, in milliseconds, we can tell what those stars are doing, why they are pulsing, and learn about the interior physics of those stars.

[Enclosure 6.]

This is the wide-field planetary camera, which has now completed its functional tests. It is in its thermal shroud, ready for insertion eventually into the space telescope. It is now undergoing its final testing, getting ready for shipment in August to Goddard. There have been problems with this. In March of this year the charge coupled device [CCD] systems, which are the guts of the detectors for the cameras, came up with a number of problems. This is the time when you would expect these problems to come up, when they get integrated into the full-up system and you start to put light through the camera system and see the results.

The last 3 months have been heavily involved in solving that problem. It has been solved. We now know the fix for those CCD's. The fixes are being implemented, and we anticipate when it will be shipped to Goddard in August.

[Enclosure 7.]

The faint object spectrograph is also ready for its final testing. It is at the Martin-Marietta Co. now and if not tomorrow, later this week, will go into the thermal vac test for its final testing at Martin-Marietta before shipment to Goddard. Again, we anticipate receiving it in August of this year.

On the faint object spectrograph we have also had detector problems. What is known as the red detector was seriously degraded. That detector is being changed out and will be replaced. We are also watching what is called the blue detector. If it degrades any further, it also will need to be replaced.

We believe we know why these detectors have failed and that by replacing them with new units they will be in good shape. That effort is proceeding.

[Enclosure 8.]

This shows you the high-resolution spectrograph. At this point you must wonder why an instrument can cost so much or what is inside. These boxes are all the same design for the actual instruments, about 3 by 3 by 7, and weigh roughly 700 pounds with an instrument inside. The handles allow the astronaut to remove these units on orbit, for replacement should one of these instruments fail.

This is one of the famous latch points which Dr. Lucas mentioned and which has been of prime concern. It is absolutely essential that these latches go in in perfect alinement and hold the instrument extremely stable, so that we can get the pointing control out of the total telescope system. The optical paths must remain totally alined within the telescope and the instrument, and then, of course, we must maintain fidelity through the data transmission back to ground.

[Enclosure 9.]

Looking inside, we show you here the buildup so you can get some understanding or feel for what is inside one of these telephone booths. This is the basic shell, aluminum structure, for the high resolution spectrograph.

[Enclosure 10.]

The critical piece of it is what we call the optical bench. This is made of the graphite epoxy material, which has a very low thermal expansion, so when this material sees different temperature changes, it doesn't flex, bend and get things out of optical alinement.

This has been one of the challenges of the program, along with the detectors. Degassing is also a problem with these epoxys. All the material now that is in critical places has been baked out, to get any moisture out, so that when they are finally integrated in the space telescope we will not have a problem with contamination.

[Enclosure 11—detector assembly.]

This is a close-up view of the detector assembly. We are having a problem with one of the detectors in the high-resolution spectrograph. It has been noisy; that is, when you are not looking at an object, you still get some current or output from the tube. It is a bad tube in that sense. It is unflyable. We are replacing it and expect the new tube to perform well.

We understand the reason why the old tube was noisy and have corrected it. It was a basic problem with some of the materials and the physics involved with that material.

This, again, is now at Goddard and ready for its acceptance testing.

[Enclosure 12.]

Then the electronics come together in the base shell with the optical bench installed.

[Enclosure 13.]

Final buildup, thermal heat dissipation mechanisms, the interfaces to the external command and data handling systems, and then finally it is buttoned up and ready for shipment.

Now that you see one of these black boxes, as they are called, I hope you will have some appreciation for what is inside and understand why we are having problems.

[Enclosure 14.]

At Goddard we are getting ready for what is called the verification and acceptance of the instrument on the high-speed photometer, the first instrument which has been delivered to Goddard. Most others will be there this summer, with the faint object camera, the last to be delivered coming in October.

At Goddard we test each instrument individually with the science instrument command and data handling system, which will be part of the ST assembly. Each instrument will be tested to be sure that it works well with the flight on-board computing and data handling system.

After each instrument is individually tested, toward the end of this test phase, we will put all the instruments together with the command and data handling system, to be sure they play as a unit. We will put them through their paces, using the instrument flight software and the flight command and data handling system. It is a systems checkout of the instrument assembly.

After that is over—and we anticipate this will be about midsummer of next year—those instruments will be shipped to Lockheed for the assembly and verification tests at Lockheed and the buildup of the space telescope.

[Enclosure 15.]

The other portion which Goddard has responsibility for is the ground system and eventually the operations of the space telescope after launch. I mentioned before the path of the data through TDRSS, White Sands, up through domestic satellite, to the NASA ground terminal at Goddard. There the information splits.

Within Goddard at Greenbelt, in the ground system, we have what is called the data capture facility. This is, in essence, large tape recorders which take all the data coming down from the telescope and record it immediately.

From there, some of the data is sent to the science institute where, as Dr. Giacconi mentioned, they will do the analysis of the data from the instruments, including getting it set for the scientists to use.

The other activity at Goddard is the payload operations control center and science support center, which together are responsible for sending the commands to the spacecraft, watching the health and safety of the spacecraft, actually being sure that it is operating in an optimum mode. We take from the science institute the observing plans and schedules and experiment commands. They come through here, back through the ground terminal, through the TDRSS, on up to the telescope.

Tying all this together, although it looks simple, has been a major challenge. There are many software contractors involved. We have CSC, IBM, Ford Aerospace, CTA, and TRW.

One of the challenges that we have is to be sure that all this software computer material plays together by the time the space telescope flies, which says you have to test all these systems with the complete system, the ground system, the satellite, and the space telescope.

The schedule, I feel, now is more comfortable than it was. On the previous schedule, it was tight. With the current launch date of June 1986, I believe we have adequate time to assure ourselves that all the pieces of this are going to play together. In fact, in this area there is maybe a little too much time.

The Data Capture Facility and Payload Operations Control Center software is coming along at good pace. We need to keep these people on as we get into the test phase, so we have slowed down some of that schedule a little bit to assure ourselves that the development meets our schedule and we are not wasteful of the people's time. So, that is being phased so that will be on an optimum schedule to work with the full-up testing of the ground system and then with the space telescope and the TDRSS.

The science operations ground system is a concern. Dr. Giacconi was talking about that. I share his concern. It is an area that we are working very closely with Marshall and are now relooking, the fiscal years 1983 and 1984 funding levels, which we will complete over the next several weeks. We will assess whether or not we are on an optimum schedule and budget for that software development.

I concur in Dr. Giacconi's assessment that the institute came in too late in that development. The funding for that was initially estimated at about $30 million. It is currently budgeted at about $42 million. I expect by the time we finish the first phase we will be at about $45 to $50 million on that.

Earlier science input from the science institute would have told us, probably several years ago, that we would have needed a system that indeed is just about where we are now. The Science Institute involvement in the management of that contract through us with TRW I think is proving very beneficial. We have good relationships with the science institute and are working in a very cooperative mode in getting this ground software in shape to support a top notch space telescope.

[Enclosure 16.]

The Payload Operations Control Center at Goddard is shown here. We are starting to put the consoles in and are well underway to having that in place and software up and ready for flight.

[Enclosure 17.]

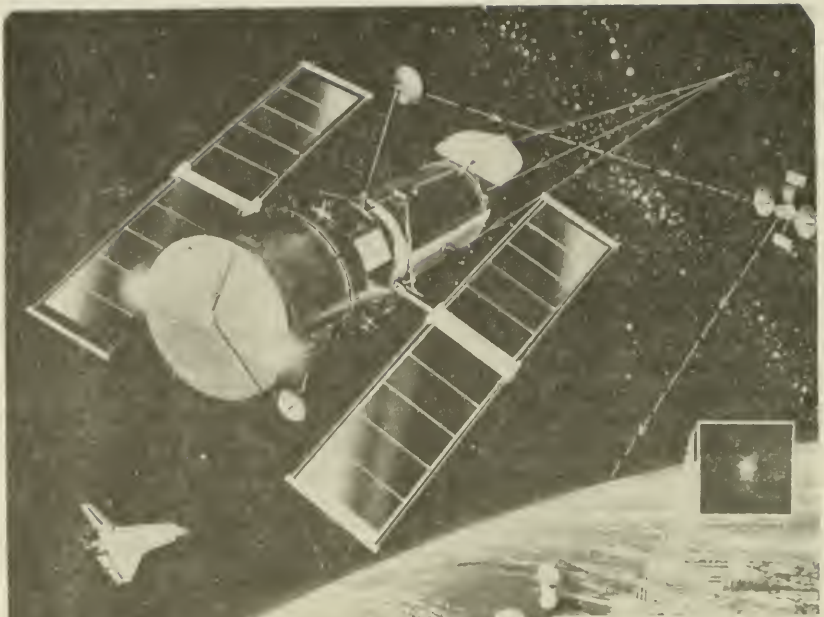
Last, the science institute itself will be dedicated tomorrow. We anticipate that as the people move into here from their dispersed locations, we will have a more compact organization, which will help also on the management interfaces.

In summing up, I think we are in good shape. Our concern is on the science operations ground software. With a scheduled relaxation, we have more time to work those problems, but we do have to work carefully the funding levels for these near-in years.

Typically, ground systems software development has lagged and has come up at the last minute in development projects. I think we need to be sure that this time we are ready well ahead of flight to go with an all-up space telescope system.

Thank you.

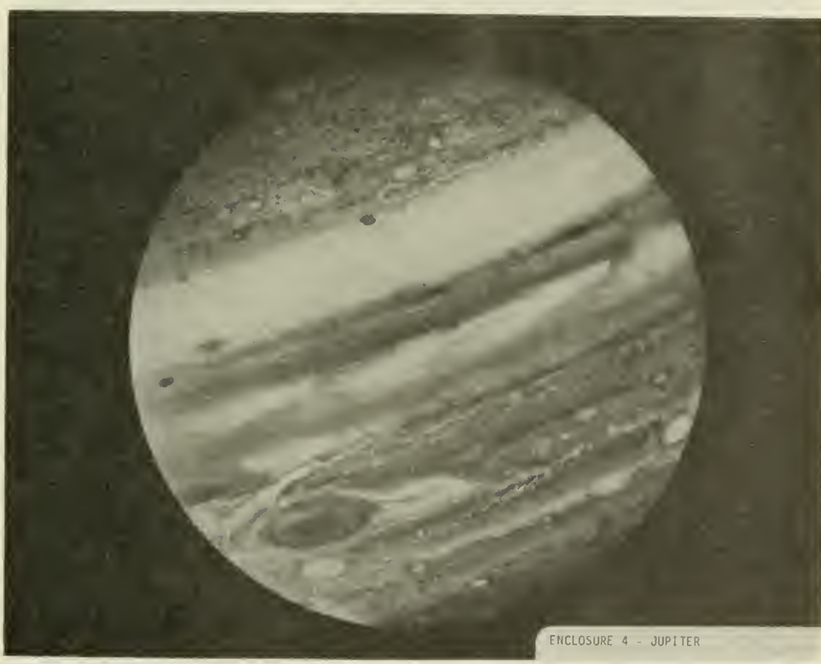
[Enclosures 1 to 17, the prepared statement, plus answers to questions asked by Dr. Hinners follow:]



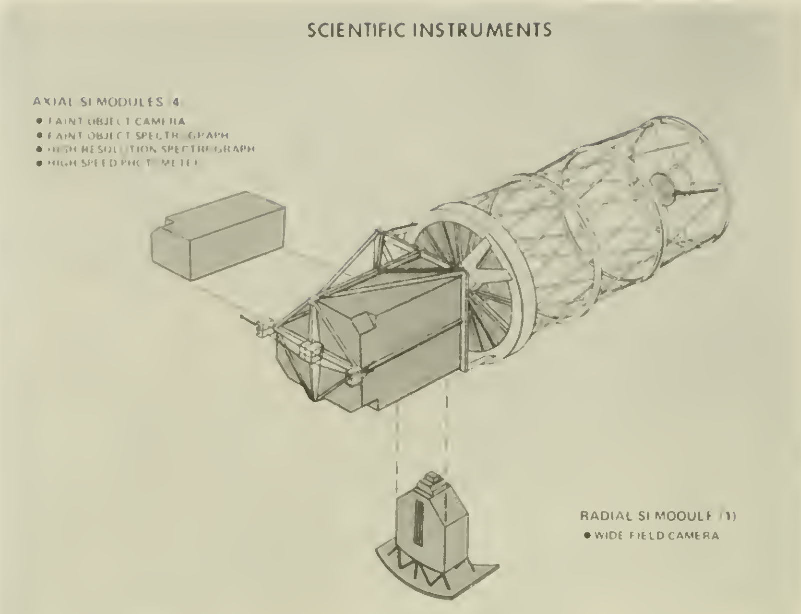
ENCLOSURE 1 - SPACE TELESCOPE

ENCLOSURE ... ST TO EXPAND OBSERVABLE
UNIVERSE BY 350 TIMES

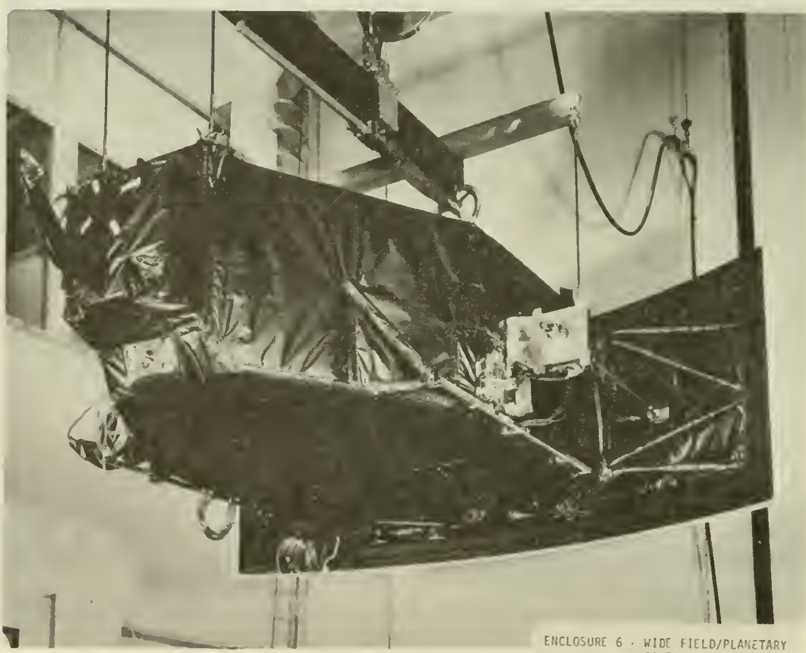
ENCLOSURE 3 - ST RESOLUTION CAPABILITY



ENCLOSURE 4 - JUPITER



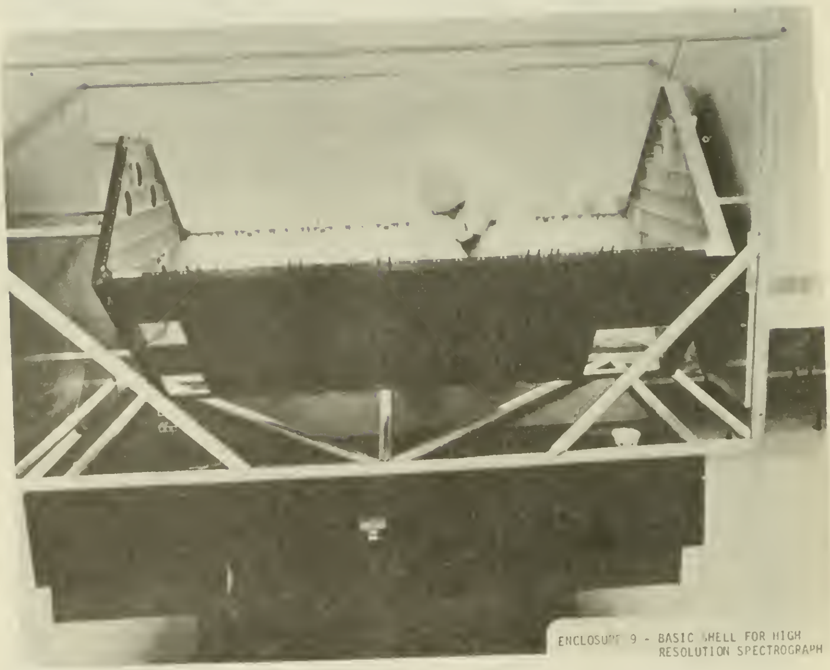
ENCLOSURE 5 - SCIENTIFIC INSTRUMENTS



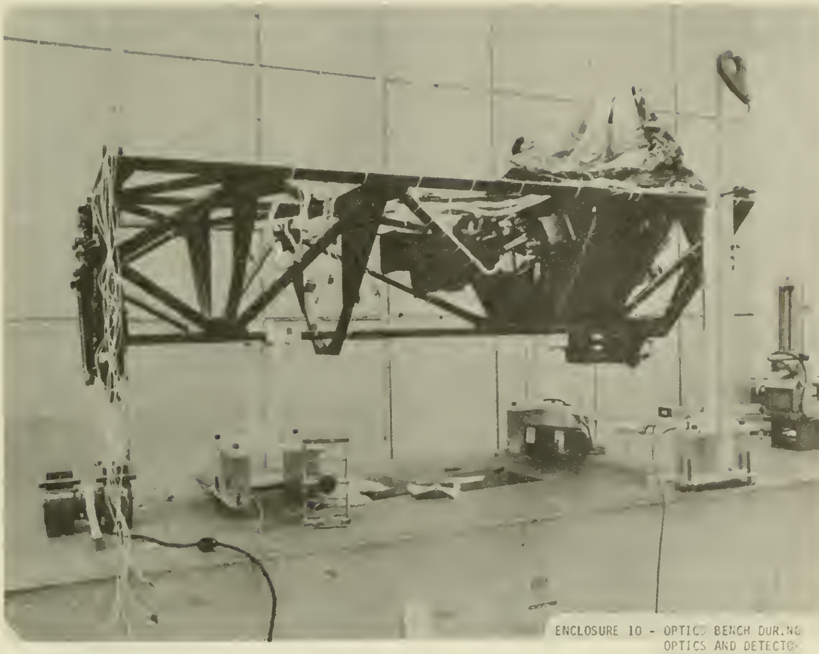
ENCLOSURE 6 - WIDE FIELD/PLANETARY CAMERA

ENCLOSURE 7 - FAINT OBJECT SPECTROGRAPH

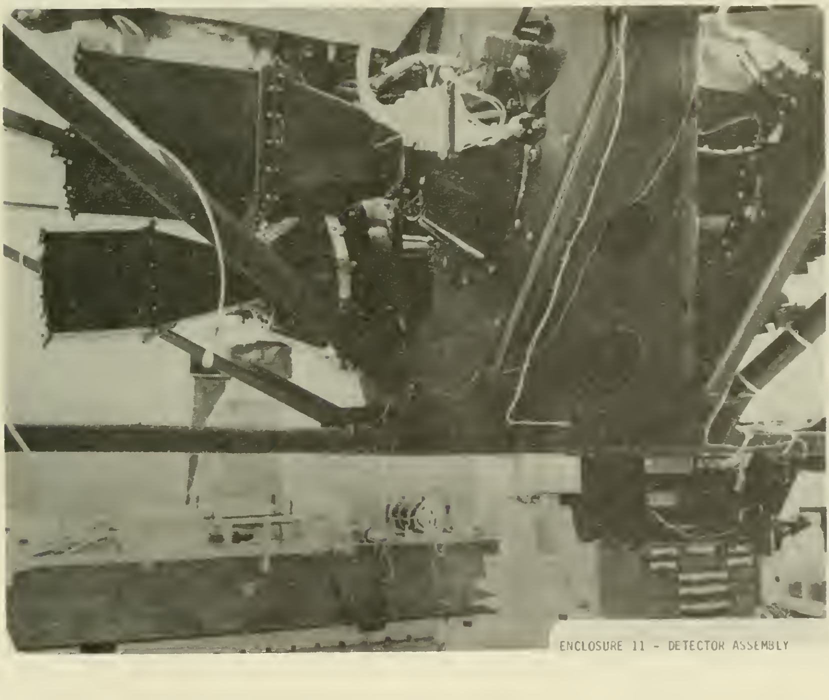
ENCLOSURE [illegible] - HIGH RESOLUTION SPECTROGRAPH



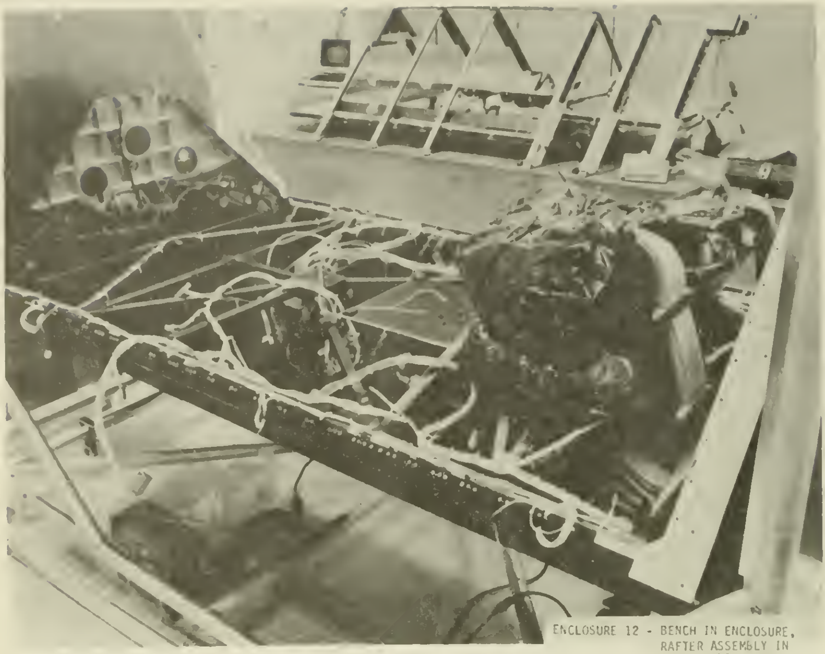
ENCLOSURE 9 - BASIC SHELL FOR HIGH RESOLUTION SPECTROGRAPH



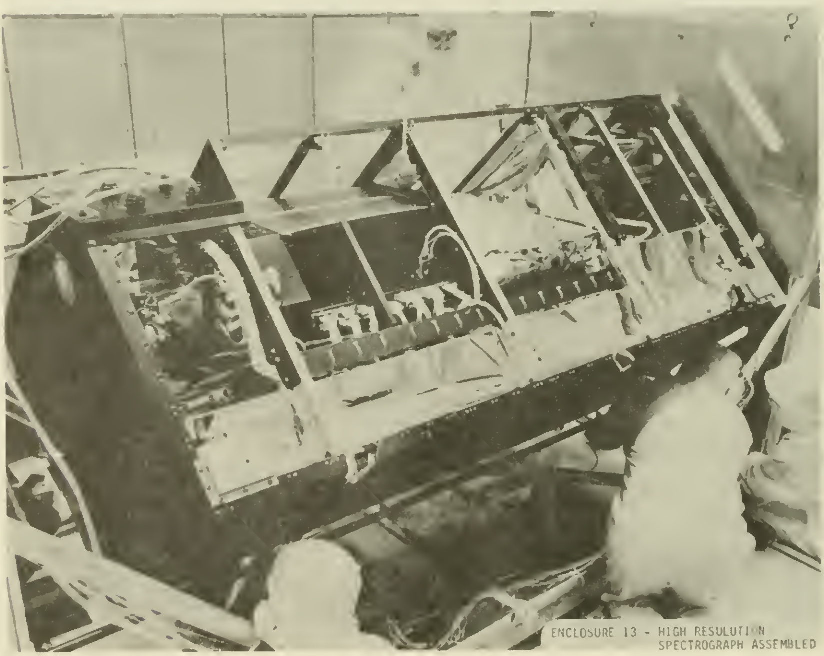
ENCLOSURE 10 - OPTICS BENCH DURING OPTICS AND DETECTOR ALIGNMENTS



ENCLOSURE 11 - DETECTOR ASSEMBLY

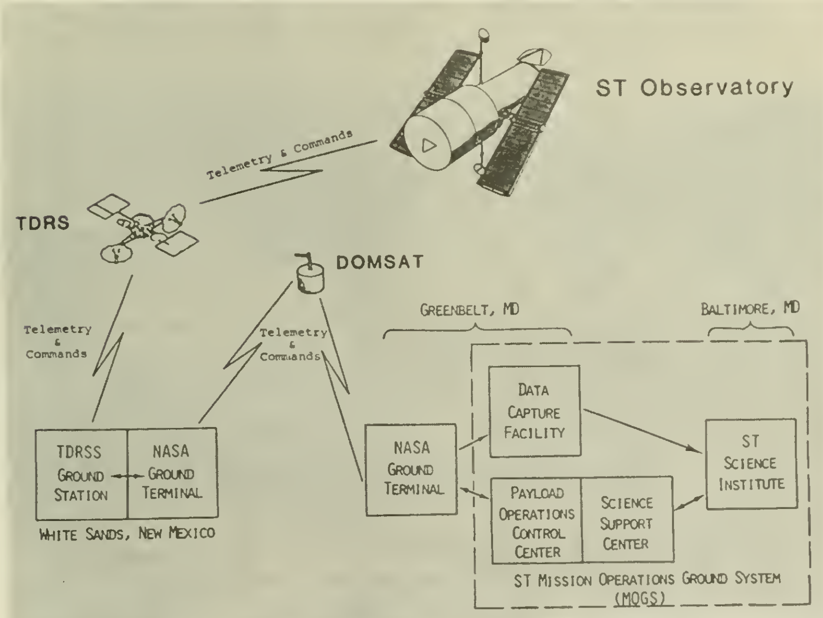


ENCLOSURE 12 - BENCH IN ENCLOSURE, RAFTER ASSEMBLY IN BACKGROUND



ENCLOSURE 13 - HIGH RESOLUTION SPECTROGRAPH ASSEMBLED

ENCLOSURE 14 - HIGH SPEED PHOTOMETER



ENCLOSURE 15 - ST GROUND SYSTEM

ENCLOSURE 16 - [illegible]T OPERATIONS CONTROL CENTER

ENCLOSURE 17 - [illegible] SCIENCE INSTITUTE

Statement of

Noel W. Hinners
Director, Goddard Space Flight Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

before the

Subcommittee on Space Science and Applications
Committee on Science and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

This statement presents the status of the Space Telescope activities for which the Goddard Space Flight Center has primary responsibility. It includes a description of the problems that have occurred, the current technical and schedule status of our activities, as well as the challenges and risks that we will face as we complete our crucial and significant responsibilities within the Space Telescope Program.

Introduction

Let me begin by describing Goddard's role in the Space Telescope endeavor. Space Telescope, in a systems-sense, begins and ends with science. It begins with the collection of scientific data and ends with the analysis and publication of scientific findings and discoveries. Goddard is intimately involved with both aspects. We are responsible for the production of the four U.S. Science Instruments which will perform the measurements. We are charged with monitoring and interface management of the fifth Science Instrument for which the European Space Agency has production responsibilities. Secondly, Goddard is responsible for the development and operation of the total ground system which will permit the conduct of astronomical research by the scientific community. Finally, we will have responsibility for operating the Space Telescope over an anticipated 15-20 year life.

As you are aware, overall project management responsibility for Space Telescope rests with our sister center in Huntsville, Alabama, the Marshall Space Flight Center. In its simplest form, the Space Telescope Project consists of four major elements: The Science Instruments, the telescope assembly, the support systems, and the ground system. Goddard is responsible for the first and last of these elements, representing about 40% of the total Space Telescope budget,* while Marshall has responsibility for the telescope and support systems in addition to their total Project management responsibility.

*development and operations, FY 1984 Budget Submission

Science Perspective

Before addressing our problems and status, I would like to offer some views and perspectives on the science capabilities and opportunities to be provided by Space Telescope.

With the launch of the Space Telescope, a decades-old aspiration of astronomers will be fulfilled, namely to be able to observe the universe with a telescope of large aperture and high-optical quality, operating in an environment free from the turbulence, selective absorption at ultraviolet and infrared wavelengths, and brightness of the Earth's atmosphere. The Space Telescope will provide a quantum improvement over current capabilities by a factor of 10 in our ability to resolve fine detail in complex sources such as the atmosphere of Jupiter or the rich star fields of nearby galaxies. For example, the images obtained of Jupiter day after day with the Space Telescope will be comparable in resolution to those obtained by Voyagers 1 and 2 when they were only a few days from closest approach to the planet. Thus, with Space Telescope, we will be able to follow the dynamics of the Jovian atmosphere over the long term.

The combination of a large light-collecting aperture (40,000 cm^2) and fine angular resolution (0.1 arcseconds) provides another quantum jump by a factor of 7 to 10 in the distances to which astronomical objects can be detected and studied. In particular, it is expected that galaxies and quasars will be observed over distances which are a large fraction of the distance traveled by light during the age of the universe--that is, we will be able to observe the universe as it was early in its lifetime. This capability will give us important clues about the large-scale structure of the universe (for example, whether it is "open" or "closed") and also about the way matter has evolved over the age of the universe. At ultraviolet wavelengths, the large aperture of the Space Telescope will permit spectroscopists to analyze the light from planets, comets, stars, nebulae, galaxies, and quasars, with resolution and sensitivity which exceed by a substantial margin the capabilities of past and current space observatories such as Copernicus and International Ultraviolet Explorer.

Because of the absence of atmospheric turbulence, we will be able to accurately measure and time the rapid changes in brightness of supernovae and novae and of the matter falling onto neutron stars and black holes within x-ray binary stars. The stability and quality of Space Telescope images will also allow the relative position of stars to be measured with improved accuracies of factors 7 to 10. Such measurements will be applied to the search for systems of planets around nearby stars.

Because of these quantum jumps over current capabilties, the change in our perception of the universe which will be engendered by the Space Telescope can be likened to that which occurred when Galileo first observed celestial objects through a simple telescope. It has also been compared to the revolution which began in the sixteenth century when the great Danish astronomer Tycho Brahe achieved a factor of 10 improvement in the accuracy of the measured positions of stars and planets. His measurements were used by Kepler to deduce the laws of planetary motion, and Kepler's work in turn led Newton to the discovery of the law of universal gravitation. The scientific program of the Space Telescope will certainly represent a climax of the revolution of modern thought about the universe, which began in the 1920's with Harlow Shapley's demonstration that our sun is not at the center of the system of stars we call the Milky Way galaxy and which continued with Edwin Hubble's discoveries that our galaxy is but one of billions of "island universes" which are expanding away from each other--an expansion we now believe to have begun in a "big bang" origin of the universe some 15 to 18 billion years ago. Perhaps our greatest excitement about the promise of Space Telescope, however, is reflected in an unofficial motto we have used within the Space Telescope Project, "conscious expectation of the unexpected." As with all revolutionary steps in observational or experimental capabilities in science, the Space Telescope will provide answers to fundamental questions we do not yet know how to ask.

At the scientific heart of the Space Telescope is an optical telescope of unparalleled quality with five powerful and versatile Science Instruments. These Instruments include two cameras, two spectrographs, and a photometer. Their capabilities are briefly summarized as follows:

Cameras: These Instruments are intended to measure the spatial structure, brightness, positions, and angular velocities of celestial objects. The Wide Field/Planetary Camera has been developed by the Jet Propulsion Laboratory, Pasadena, California, under the direction of Principal Investigator James A. Westphal of the California Institute of Technology. It is sensitive over an extraordinary wavelength range, from 115 nm to 1100 nm, but it is most sensitive in yellow-to-red light. It has been designed to observe relatively large fields of view (sufficient, for example, to encompass the entire disc of Jupiter) at a small sacrifice in angular resolution. These capabilities are complemented by those of the Faint Object Camera, developed by the European Space Agency. This camera attains the highest possible angular resolution at some sacrifice of field of view and is most sensitive at ultraviolet and blue wavelengths.

Spectrographs: Spectrographs are the primary tools of modern astrophysics, allowing scientists to analyze the light emitted by celestial objects to deduce their physical nature--that is, their chemical composition, temperature, density, radial and rotational velocities, etc. The two spectrographs on board the Space Telescope will make up a complementary set, covering a remarkably broad range of capabilities.

The Faint Object Spectrograph has been built by the Martin Marietta Corporation under contract to the University of California at San Diego, with Richard J. Harms the Principal Investigator. It will provide high-quality spectroscopic data on exceedingly faint objects at relatively low spectral resolution. The High Resolution Spectrograph, managed by Goddard under Principal Investigator John C. Brandt, was built by Ball Aerospace Systems Division, Boulder, Colorado. In one mode, the High Resolution Spectrograph will provide a spectral resolution which is unprecedented in space astronomy on relatively bright objects. In another mode, its sensitivity will greatly exceed that of the Copernicus and International Ultraviolet Explorer instruments at comparable spectral resolutions. Both the Faint Object Spectrograph and the High Resolution Spectrograph will exploit the image quality of the Space Telescope to isolate specific target objects in crowded fields of view. The High Resolution Spectrograph is exclusively an ultraviolet instrument, while the Faint Object Spectrograph sensitivity extends well into the red.

Photometer: The High Speed Photometer was built at the University of Wisconsin, under the leadership of Robert C. Bless, Principal Investigator. This Instrument will provide the ability to precisely measure variations in the brightnesses of stars which are in the last phases of their evolution or to follow the dimming of light from a distant star as it is occulted by the atmosphere of a planet in our own solar system. It can distinguish variations separated in time by as little as 32 microseconds. It will also achieve an improved precision with which the brightness of non-variable stars are measured.

In addition to these five dedicated Science Instruments, the Fine Guidance Sensors, which provide positional stability information to the spacecraft, also will be used for an important scientific purpose--to greatly improve our knowledge of the relative positions and distances of stars and other objects within their fields of view. This type of research is called "astrometry." Implementation of the Fine Guidance Sensors astrometry program is the responsibility of Principal Investigator William H. Jeffreys of the University of Texas, under contract to the Marshall Space Flight Center.

It should be noted that the Space Telescope is intrinsically capable of supporting certain types of infrared observing programs, though instrumentation for this purpose was not selected for the initial flight. Except for the infrared, the Space Telescope (with the initial complement of Instruments descibed here) will be a complete observatory. It is difficult to think of any category of optical astronomical observations which cannot be conducted with one or more of the current Instruments. Moreover, these Instruments are capable of providing quantitative data of superb quality, since they are all characterized by their stability, high sensitivity, wide dynamic range, and low background noise levels.

We consider the Space Telescope to be a first, essentially-permanent space observatory. With Shuttle-supported maintenance, altitude reboost, and possibly refurbishment, its mission lifetime can be one-to-two decades. However, there is no a priori reason why it could not continue to operate well beyond that period, while providing a major continuing capability to astronomers of the 21st century.

To foster the long-term continuity of the Space Telescope observatory, NASA has entered into a unique partnership with the astronomical community by contracting with the Association of Universities for Research in Astronomy (AURA) to manage the scientific program of the Space Telescope. This contract is administered by Goddard. The Space Telescope Science Institute, the earth-based site for scientific operations of this space observatory, will open the doors of its permanent facility at the Johns Hopkins University in Baltimore, Maryland, on June 15, 1983. The Institute will need many tools to accomplish its mission. In particular, a versatile and powerful set of computer hardware, peripherals, and software, constituting the Science Operations Ground System, is required. The Ground System will provide the means to plan and schedule the observations, to implement real-time operational commanding, to supply quick-look data processing and displays, to convert the data telemetered down from the Space Telescope into a reduced and calibrated form amenable to scientific analysis, and to furnish individual scientists who come to the Space Telescope Science Institute with a versatile menu of analysis software with which to begin the process of scientific interpretation. The Science Operations Ground System is being developed by TRW, Inc., Redondo Beach, California, under contract to the Goddard Space Flight Center.

Science Instruments Progress

It has been nearly six years since the Space Telescope Project began. In that period, we have come a long way, though there is much yet to be done. The efforts for which Goddard is responsible have come from mere glimmers in the eyes of astronomers-instrument scientists to nearly completed Science Instruments. While none of the five Science Instruments planned for the initial flight of Space Telescope are today completely ready for launch, each of the four U.S. Instruments have in fact been built, assembled, and have demonstrated an all-up operational capability. They operate as instruments. They are no longer a mere glimmer or a paper design or a collection of nuts and bolts. Each of them has demonstrated that, as instruments, they perform their intended purpose and function. Not all have completed their instrument-level test phases yet, but all have at least begun, after first demonstrating optically and electrically that they can indeed function as designed and as advertised.

The fifth Instrument, being developed by the European Space Agency, is not quite as far along, since it had been dealt a substantial setback about 1-1/2 years ago because of the discovery of a generic manufacturing defect in its vidicon tubes. Nevertheless, the European Space Agency and its contractors have largely recovered from that technical setback and are now nearing the point when the entire Instrument will be assembled and functioning, as well as environmentally tested.

I do not want to give the impression that the development of these Instruments over the last six years has not been without technical problems; indeed, some are still occurring. Many of these problems are of the typical variety and in the usual quantity associated with large hardware developments. Each of the Science Instruments, by the way, is roughly the size of a phone booth, that is, about 3 X 3 X 7 feet and weighing 700 pounds or so. They all incorporate optical systems and sophisticated electronics—some with built-in microprocessors, and advanced materials to provide the needed thermal and structural precision and stability. It was not long ago that complete orbiting spacecraft were of the size and sophistication of each of these Space Telescope Instruments. Thus, one reasonably expects some hardware development problems in frontier technological efforts such as this.

To illustrate this point, one such problem involves the Wide Field/Planetary Camera. This instrument utilizes eight separate camera heads used in groups of four to acquire either wide-field-of-view or high-resolution pictures. Each camera utilizes an advanced solid state detector called a Charge Coupled Device. These devices are used in order to provide high resolution and large sensitivity over a wide wavelength range. They were developed by the Texas Instruments Company for the Space Telescope and Galileo Programs and are cooled to $-95^{\circ}C$ in order to function. The problem began to surface during electrical performance testing on one of the eight cameras. Subsequent technical investigations, tests, and analysis identified the cause to be due to the <u>combination</u> of three separate factors: a manufacturing technique (a coating applied to the Charge Coupled Device), the camera's thermal test history, <u>and</u> its exposure to ultraviolet test sources. Together, these factors combined in just the wrong way to significantly degrade the detector's performance. Further, all other detectors were determined to be similarly susceptible to the same degradation. The scientists and engineers, after discussions with the manufacturer's technical experts and several experimental tests and theoretical modeling, have developed and implemented a cure for the phenomena. There are two key points associated with this example: first, there can be and are very subtle but critical problems to be encountered with advanced state-of-the-art instruments; and, second, this problem was encountered just three months ago (March 1983)--not three or six years ago. It was uncovered by methodical and careful testing (that is what testing is for), and it was solved by skilled and dedicated people. Because the on-orbit research capabilities of Space Telecope require that we carefully test or reanalyze that which we cannot test on the ground, we can, I believe, reasonably expect to uncover some more "high-tech unknowns." This process will continue over the next few years as we complete our testing on individual Instruments and as we move on to testing of Instruments in conjunction with their flight command and data handling and software systems. Ultimately, the process will continue into the systems-level test phase where Space Telescope will be operated on the ground as an all-up functioning entity in order to proof-test its basic operations functions and capabilities. Our challenge will be to continue to do this carefully and well and to be sufficiently skilled and innovative to quickly overcome the technical problems which are bound to arise.

Let me now describe in some detail the status of our Instruments and related hardware and testing.

Science Instrument Status

The flight instrument program at Goddard has just begun a series of tests which will integrate the five Instruments with the Command and Data Handling equipment they will use in the Space Telescope. This testing will be accomplished after each Instrument completes its environmental test program and will insure that the Instruments, as a system, will not interfere with each other when operated in the Space Telescope observatory. The flight software will also be verified as part of this process. The instrument test program will culminate early next year in a functional test of all five Instruments together, simulating the various modes of operation that they will be expected to perform in orbit. This will be the final set of tests on the Instruments before delivering them to the Lockheed Missiles and Space Co., Inc., Sunnyvale, California, for integration into the Space Telescope.

This program has just started at Goddard. The Command and Data Handling equipment, built by the Fairchild Space Company, Germantown, Maryland, has been delivered to Goddard after completing its environmental qualification testing. The onboard computer, which will operate with each of the Instruments, and the extensive ground equipment needed to perform the Verification and Acceptance Program testing at Goddard have also been delivered. This equipment, developed and supplied by the IBM Corporation, Germantown, Maryland, is now hooked up to the first Instrument, the High Speed Photometer (which was delivered last year and has already completed its environmental test program).

The High Resolution Spectrograph has just been delivered to Goddard after having completed alignment, calibration, and thermal vacuum testing. It will now be tested at Goddard to the mechanical environments before beginning the Verification and Acceptance Program testing in July.

The Faint Object Spectrograph has completed alignment, "ambient" calibration, most of the structural/mechanical qualification tests, and is now ready to begin thermal-vacuum testing and calibration. It is scheduled for delivery to Goddard in early August.

The Wide Field/Planetary Camera will be delivered to Goddard in late August. It has completed alignment and the first of two planned thermal-vacuum tests. Modifications to the cameras required by problems found last March have also been completed. Structural/mechanical testing has now started, to be followed by the second thermal-vacuum and calibration test before delivery in late August.

The Faint Object Camera, mentioned earlier, is supplied by the European Space Agency. This Instrument, in a configuration in which all hardware except the detector assembly was "flight" equipment, has completed all environmental alignment and electromagnetic interference tests. The "flight" detector assembly is now being installed; and, over the summer, the Faint Object Camera will repeat the acoustic and thermal vacuum tests and perform its final calibration. The Faint Object Camera will be delivered to Goddard for the Verification and Acceptance Program testing in late October.

To summarize the current status, one Instrument (the High Speed Photometer) and the Science Instrument Command and Data Handling equipment have completed their acceptance programs as individual subsystems. Three Instruments (the Faint Object Spectrograph, the High Resolution Spectrograph, and the Wide Field/Planetary Camera) have been operated in their flight configuration and are now in the environmental test phase. The fifth Instrument (the Faint Object Camera) is now being integrated into its final flight configuration. Finally, the test program, which will test all of the Instruments as a complete science system, has started at Goddard.

We have several technical deficiencies, all of which are correctable. The significant ones are:

- One of the two detector assemblies of the High Resolution Spectrograph exhibits sufficient noise, such that a determination has been made that, if flown, it would significantly degrade the science return. Investigations completed earlier this year showed that the problem was associated with a high-resistance coating applied externally to the digicon tube. A replacement detector assembly has been built and is exhibiting low-noise characteristics. Changeout, retest, and recalibration is scheduled for next fiscal year, without impact to the Verification and Acceptance Program testing, nor delivery to Lockheed.

- The red-sensitive detector assembly of the Faint Object Spectrograph has degraded to below acceptable limits. The cause has been traced to the combination of exposing the operating instrument to normal laboratory lighting with low voltage levels applied to the tube. This phenomena was totally unexpected by all the experts, including the co-inventors of the tube. Nonetheless, the degradation has occurred; actions are in place to preclude a future occurrence; and changeout, retest, and recalibration is scheduled for FY 1984.

  The blue-sensitive tube of the Faint Object Spectrograph has sustained slight degradation, possibly but not certainly due to the same phenomena. While it continues to perform above "scientific minimums," its performance is being carefully monitored; and we have allocated contingency funds to replace it also, should it become necessary.

- The High Speed Photometer many months ago suffered a number of problems associated with its internal power supply. At that time, it was found that this power supply--manufactured by a subcontractor--had serious design and quality defects such that it was not repairable. A brand new power supply is presently under construction at the University of Wisconsin and will be installed upon completion.

Overall, I believe that the Science Instruments are in quite good shape, with firm plans in place to correct the few remaining technical problems.

Development of Ground System

The second major responsibility of Goddard is to develop the entire ground system which will be used to operate Space Telescope and to support the user-observers through the generation of science-output-products for analysis and archiving.

The Space Telescope ground system consists of Space Telescope-unique, as well as NASA-wide, facilities. The latter, which I will not discuss here, consists of the NASA network including the Tracking and Data Relay Satellite System (TDRSS) facilities, the NASA Communications (NASCOM) facilities, and certain other general purpose equipment and capabilities.

The Space Telescope-unique ground system facilities reside in two principal locations: at Goddard in Greenbelt and at the Johns Hopkins University Homewood Campus in Baltimore, Maryland.

At Goddard, we will have the Space Telescope Operations Control Center (STOCC) at which the health and safety of the orbiting telescope will be maintained; command, control, and communications management will take place here. Continuous engineering assessment of the performance of the entire system will be done by the personnel at the "STOCC," and they will also provide the interfacing functions with NASCOM, the TDRSS, and the second principal facility, the Space Telescope Science Institute. At the Space Telescope Science Institute, the observing program will be managed; the science data will be received, calibrated, and archived; and science data analysis will be supported through the generation of science data products. These two facilities, at Goddard and at the Johns Hopkins University, will provide the capability to operate Space Telescope in orbit for the purpose of scientific research by the astronomical community.

A few comments about the status of each of the major components of the ground system are appropriate:

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Facility modifications at Goddard for the Space Telescope Operations Control Center (STOCC) have been completed, and this space is now becoming occupied by consoles and computers, as well as by the advance planning staff of the mission operation contractor, Lockheed Missiles and Space Co., Inc. The hardware and software systems to be installed in the Goddard STOCC will provide the capability to directly control the Space Telescope from the ground and to analyze the performance of the onboard engineering systems. Implementation of this capability is being accomplished under two contracts (the Computer Science Corporation, Silver Spring, Maryland, and Ford Aerospace, College Park, Maryland) and is managed by Goddard. Progress on this system is running substantially ahead of project need dates.

Whereas the above might be considered to be an "Engineering Operations Ground System," the "Science Operations Ground System" is being developed by TRW (mentioned earlier) for use by the Science Institute. It consists of a network of computers, associated control and display terminals, and a system of computer programs to support observation planning and scheduling and post-observation data processing. Design is nearing completion, and many of the hardware components have been delivered. The formal critical design review was held in March 1983, and software coding has begun. The Space Telescope operation activities will be rephased consistent with the revised launch schedule.

The Space Telescope Science Institute is operated by the Association of Universities for Research in Astronomy (AURA) under contract to Goddard. The Science Institute was created to administer and conduct the Space Telescope Science Program, beginning with Announcement of Opportunities through conduct of observations and production of processed data.

The Science Institute staff is now housed in a newly constructed facility on the Johns Hopkins University Homewood Campus in Baltimore, Maryland. In fact, the official opening of the facility will take place tomorrow, June 15, 1983. Prior to the availability of this Space Telescope—dedicated facility, the evolving staff of the Science Institute have been temporarily housed by Johns Hopkins University.

One of the Science Institute's challenges over the past several years was to evolve from a concept to an operational organization. Besides the building, they had to begin hiring personnel, create an infrastructure capable of such things as purchasing, accounting, payroll, janitorial and security services, as well as to provide the technical expertise to develop two essential elements of the ground system: the capability of selecting suitable guide stars for observational use and an interactive analysis software system for scientific information extraction from the telemetered data.

During the past year, significant progress was made by the Science Institute staff in developing the Guide Star Selection System, which will be used to create a required guide star catalog which is more precise and contains fainter objects than presently existing catalogs. The Science Data Analysis System is the other major system development activity being carried out by the Institute, and good progress has been made as well in the design of the software for this system.

Together, these two essential elements of the Space Telescope ground system represent about a seven-million-dollar development effort which is currently engaging roughly one-third of the Science Institute staff. Another one-third or more is engaged with administrative (accounting, business support, etc.) and management functions. The remaining staff is participating in operations planning.

Our current problems in the ground system development activity center around the challenge to build an appropriate science operations ground system capability. This effort is a large and, in some respects, pioneering effort. While much of the effort is progressing satisfactorily, the March design review served to point out some weaknesses, particularly in the automated science planning and scheduling approach. A reexamination of that approach is currently underway, and we expect to have corrective actions in place within the next few months.

Overall, the development of the ground system for Space Telescope is progressing, and there is no reason to expect that we will be anything but fully ready and capable of supporting the launch and operations of Space Telescope.

Concluding Remarks

In summary, the Goddard Space Flight Center has a significant and crucial role to play in the development and operations of the Space Telescope. We plan to provide Science Instruments fully capable to deliver promised and perhaps unimaginable science, and we will provide a ground system which is fully capable of exploiting the science potential of those Instruments. Many significant milestones have already been achieved, including the fact that four flight Instruments exist. And, while Space Telescope is truly "cutting-edge technology" with much work to be done and new technical problems to be solved, Goddard has the resources and capability to successfully complete our assigned responsibilities.

To assure proper attention to this high-priority NASA mission, last November (before the current overall Space Telescope problems surfaced), we restructured the Space Telescope Project at Goddard. The Project Manager was elevated to Deputy level in our project organization and added to the staff were senior personnel, many of whom were leaders in developing the International Ultraviolet Explorer, now in its sixth year of operation and a prototype of sorts for the Space Telescope.

Thank you very much, Mr. Chairman.

Written Questions submitted by Chairman Volkmer during the June 14, 1983, hearing at which Dr. Hinners testified.

QUESTION 1:

a. Dr. Hinners, could you describe the Goddard organizational structure for the Space Telescope activities?

b. Are the Space Telescope activities at Goddard within a single project office?

c. Does each instrument have a separate project manager?

ANSWER 1:

a. The Space Telescope projects resides within the Flight Projects Directorate at the Goddard Space Flight Center (GSFC). Recently, the project was elevated to Deputy Director of Flight Projects level. The Deputy Director of Flights Projects for Space Telescope has a direct line to the center director for all matters relating to the Space Telescope. Aside from the project manager, the project is divided into five main offices, namely: Systems Engineer, Science, Resources, Experiment Systems, and Ground Systems and Operations. Each of the office managers for Space Telescope reports directly to the Deputy Director of Flight Projects. Each of the five main offices has, in turn, its own respective staff.

Supporting the Space Telescope project are the other Goddard Directorates, namely: Management Operations Flight Assurance, Mission and Data Operations, Science, Engineering, and Networks.

b. The Space Telescope activities at Goddard are organized within a single project office.

c. Each instrument has an assigned technical officer who is responsible for overall performance of his respective instrument. Primarily, the technical officer coordinates all schedule and technical performance activities between the instrument contractor and the project. The contract technical officers for each of the five scientific instruments report to the instrument systems manager who is responsible for overall instrument performance.

QUESTION 2:

How would you assess the working relationship between Marshall and Goddard relative to the Space Telescope program?

ANSWER 2:

Overall, the working relationship between the Space Telescope personnel at Marshall and Goddard has been very good.

QUESTION 3:

a. Could you elaborate on the cost growth associated with the development of the science instruments?

b. What portion of the cost growth can be attributed to "inflation" and what portion to "cost overrun?"

ANSWER 3:

a. The increase in cost associated with each of the major instrument contracts can be identified in three major categories: scope changes, rephasing, and cost growth. The scientific instruments are each one-of-a-kind designs, and employ state-of-the-art technologies. The more costly increases are associated with the development, manufacturing, and testing of digicons and detectors on the faint object spectrograph (FOS), hybrids, optics, and detectors on the high resolution spectrograph (HRS), the internal power supply on the high speed photometer (HSP), electrical redesign, heat pipes, selectable optical filter assembly and filter mechanism on the wide field planetary camera (WFPC), science data formatting and hardware changes on the scientific instruments control and data handling, and overall late latch deliveries. As mentioned above, program rephasing in December, 1980, from a 1983 launch to a 1985 launch contributed a significant portion of the overall cost increase and the launch delay to 1986 will contribute an additional cost increase to the science instruments. Our analysis is not yet completed on the amount of cost increase due to the slip of the launch to 1986.

b. The detailed analysis of the rebaselining of the Space Telescope development activities will not be completed until late summer or early fall. We will, however, inform the Committee of our final assessment of the Space Telescope cost increases at that time.

QUESTION 4:

Please provide for the record and for each instrument:

a. Contractor,
b. Initial cost estimate at completion,
c. 1980 rebaseline cost estimate at completion,
d. Current cost estimate at completion,
e. Original and current date of delivery, and

f. Significant factors affecting cost increase.

ANSWER 4:

See Chart A, attached, for items a. through e. Listed below are the major cost drivers per scientific instruments:

Cost Drivers

FOS

Detector Assemblies
Digicons
Uncompensated Momentum
Hybrids

WFPC

Radiator
Filter Mechanism
Heat Pipes
Electric Redesign

HSP

Low Voltage Power Supply

C&DH

Sci. Data Format.
Std. HDW Changes
RIU

HRS

Detectors
Hybrids
High Voltage Power Supply
Optics

OTHER COST DRIVERS

Latch Deliveries
Rephasing and associated inflation

QUESTION 5:

a. What is the impact on the Science Institute and ground management system of current plans to reprogram funds from these activities to development?

b. Are you confident that the ground system and the Science Institute will be in place by the time the Space Telescope is launched?

ANSWER 5:

a. The major impact of the reprogramming of FY 1983 funds out of operations is a delay in the completion of the science operations ground system (SOGS), consistent with the rebaselined launch schedule. This will, of course, increase the runout cost of the SOGS.

Impact to the Space Telescope Science Institute has been minimized so that the presently on-board positions will not be reduced. (These positions are highly specialized, and NASA has a considerable investment in the Space Telescope knowledge now possessed by the incumbents.) However, the planned staff buildup of operations personnel has been delayed to correspond to the new launch date.

($ in Millions)

Instrument/Contractor	Initial Cost Est. At Comp.	1980 Rebase-line Est. At Comp.	Current Est. At Completion	Original Delivery Date	Current Delivery Date
Faint Object Spectrograph (FOS)/University of California, San Diego	16.2	28.1	Under Review	12/81	8/83
High Speed Photometer (HSP)/University of Wisconsin	4.3	5.5	Under Review	9/81	Delivered 7/82
High Resolution Spectrograph (HRS)/Ball Aerospace System Division	10.7	29.0	Under Review	12/81	Delivered 5/83
Wide Field Planetary Camera (WFPC)/California Institute of Technology	23.0	43.7	Under Review	2/82	9/83
SI Control & Data Handling (SI C&DH)/IBM/Fairchild Space Company	14.4	32.1	Under Review	3/82	Delivered 3/83

CHART A

b. I believe that the ground system and the Space Telescope Science Institute will be in place by the time the Space Telescope is launched. It is our current plan to achieve operational readiness 90 days prior to the June, 1986, launch readiness target.

QUESTION 6:

What is the current runout cost estimate for the Space Telescope operations budget? What was the original estimate for operations? What factors contribute to the increase?

ANSWER 6:

The operations funding will continue indefinitely based on the retrieval/refurbishment capability provided by the Space Shuttle; therefore, there is no runout cost estimate for operations. However, the runout assumed in the FY 1984 budget through FY 1988 is a total of approximately $241 million with a level of approximately $40 million per year after launch of the Space Telescope. This yearly operations level of $40 million should be compared to a level of $15 to $20 million per year assumed when the Space Telescope operations funding level was initially estimated. The increased level of yearly operations funding is the result of better definition of the Space Telescope system, definition of the required level of personnel to support operations and data analysis.

QUESTION 7:

How would you assess the reaction of the scientific user community to the Space Telescope schedule slips?

ANSWER 7:

The scientific community is understandably concerned that their opportunities to make use of the Space Telescope research capabilities have been delayed. The overriding objective of the science community is to maintain high performance requirements.

QUESTION 8:

What is the biggest challenge which lies ahead for Goddard activities?

ANSWER 8:

The flight instrument program at Goddard has just begun a series of test which will integrate the five instruments with the command and data handling equipment to be used in the Space Telescope. This testing will be accomplished after each instrument completes its environmental test program and will insure that the instruments, as a system, will not interfere with each other when operated in the Space Telescope observatory. The flight software will also be verified as part of this process.

Another major challenge is to develop the entire ground system which will be used to operate the Space Telescope and to support the user-observers through the generation of science-output products for analysis and archiving.

QUESTION 9:

In your statement, you noted that a March design review pointed out some weaknesses in the automated science planning and scheduling approach. Could you please elaborate on these weaknesses?

ANSWER 9:

The major weakness identified was concern that the science planning and scheduling system would be too automated because of lack of capability for scientists to interact when they needed; for example, to accommodate observation of a newly discovered target. Another weakness which was identified was the man-machine interface required to control the science planning and scheduling system. Both of the deficiencies are being corrected through design modification.

QUESTION 10:

If you could do it all again, would you have as many cooks in the kitchen; that is would there be as many contractors and centers involved?

ANSWER 10:

The question is an excellent one, which has been the subject of much discussion and debate within NASA. The question embodies several supports, including multiple NASA field centers as well as multiple contractors (i.e., no single "prime contractor").

I would like to address the "multiple center part" first. As you know, MSFC and GSFC are both deeply involved with the development of the Space Telescope. The MSFC has overall project management responsibilities, as well as direct management responsibility for the Optical Telescope Assembly, the support systems module, and system engineering. The GSFC has direct responsibility for the development of the scientific instruments, the development of the total ground system, and, after launch, the operation of the Space Telescope observatory.

My belief is that this is an appropriate arrangement in view of the large scale of the Space Telescope undertaking and does in fact capitalize on the respective skills and capabilities of the two centers. While this arrangement has caused some problems at the working level, which are largely due to differences of approach and professional pride, these problems have largely been overcome; a solid cooperative attitude from both sides has developed and this multiple-center involvement has not precipitated (nor fostered) the problems that have led to the present state of the Space Telescope. Consequently, I would not, "in doing it again," reject the approach of multiple-center involvement.

Regarding the question of multiple contractors, my belief is that the sheer immensity of the Space Telescope, combined with the diverse range of components (e.g., telescope, five sophisticated instruments, Shuttle-sized spacecraft, ground system, etc.), make it impractical to implement at or by any single industrial firm. The skills and capability to produce the world's finest optics differ substantially from that requested to produce a high resolution spectrograph, both of which differ from those needed to produce the 44-foot-long structure (SSM) accommodating the 25,000 pounds of equipment. So, it is necessary, I believe, to have different elements produced by different corporations.

There are some areas where improvements might have been possible, had different approaches been taken which, in some cases, would have required different circumstances to have prevailed at the time those approaches had been taken. For example, I believe that a good case for the selection of a single prime contractor could be made. It would have simplified the Government-industry interface and would have focused overall responsibility and accountability in one place. However, one would have to assume that the prime contractor would (because of scale and skills) be forced to subcontract out major portions of the effort. This would lead to additional interfaces albeit industry-to-industry; but more importantly, because of contractual arrangements, would have made NASA's oversight and penetration at the subcontractor level very difficult. Hence, it is not clear that a "prime" approach would have avoided many of the present difficulties.

QUESTION 11:

Have there been many changes made in the criteria and requirements for the software being developed by TRW? If so, what has been the impact of these changes?

ANSWER 11:

The original science operations ground system (SOGS) proposal submitted by TRW provided a basic capability. Although this capability would have supported the major mission goals, a number of system enhancements were later suggested by the Space Telescope Science Institute personnel that would improve the flexibility of the SOGS and contribute to greater scientific productivity. In particular, three areas have been substantially augmented in this regard:

- High level command language (user interface to the system);

- Image display and analysis capability; and

- Increased processing and display of instrument housekeeping data.

QUESTION 12:

What mechanisms do you use to monitor any changes in requirements and the effect on costs?

ANSWER 12:

The instrument systems manager holds the assigned technical officer for each of the instrument contracts responsible for the complete coordination of the cost, schedule, and technical performance between the project and the contractor for each instrument. The instrument systems manager, in turn, reports to the experiment systems office manager who insures that all changes in requirements are properly coordinated among the various project functions. As a tool in monitoring changes in requirements, cost, and schedule, there is a formal Configuration Control Board (CCB) which operates under formal written procedures for insuring complete coordination among the various project entities. All input is considered by the CCB prior to approval or disapproval of any action by the chairman who, in the case of the scientific instruments, is the experiment systems office manager.

Mr. VOLKMER. Thank you very much, Dr. Hinners.

I have a few questions I would like to talk to you about. One I guess is we can start right about where you ended.

As I understand it, the actual operation of the space telescope, the signals to operate it, will come from Goddard, correct, not from the institute?

Dr. HINNERS. That is correct.

Mr. VOLKMER. The institute is just there to obtain the information back?

Dr. HINNERS. The institute actually does develop the observing programs.

Mr. VOLKMER. But the signals to the telescope will go through Goddard——

Dr. HINNERS. The signals will go from Goddard through the TDRSS, right. The institute does develop the programs and observing and instrument commands that then come through us to be transmitted up to the telescope.

Mr. VOLKMER. In the instruments, which you have gone over, I believe in your testimony you set out the principal investigator and who is doing it. Could you also provide for the record the 1980 baseline cost estimate at completion and when it was done, the current cost estimate at completion, and the original and current date of delivery?

Dr. HINNERS. We can supply that for the record.

Mr. VOLKMER. Also, if there have been cost increases, what caused those cost increases.

[The information follows:]

We have interpreted the intent of this request to be to show the growth in costs since the 1980 rephasing of the ST Project (to a launch date in early 1985). The final cost plan for that rephasing was formally prepared and submitted in April 1981, and that plan is included on the attached material as the "before." The current costs shown represent our current estimates though they have not yet been scrutinized with NASA; so necessarily must be considered to be tentative at the moment.

DEVELOPMENT

COST GROWTH

REPHASED PROGRAM TO PRESENT

POP 81-1

- o REPHASED PROGRAM

POP 81-1 TO 82-1

- o SCIENCE COST GROWTH - FOS, HRS, WF/PC, AND SI C&DH

POP 82-1 TO 82-2

- o SCIENCE COST GROWTH (LATCHES, NSSC CHARGE, AND FRACTURE MECH. ANALYSIS)

POP 82-2 TO 83-2

- o SCIENCE COST GROWTH (DETECTORS CHANGEOUT, MOD THERMAL SHROUD, VAP EXTENSION, SPARES, SYSTEM ENGR.; PROGRAM STRETCH OUT

NOTE:

POP 83-1 NEVER OFFICIALLY SUBMITTED TO NASA HEADQUARTERS

DEVELOPMENT

POP RUNOUT SUMMARY
REPHASED PROGRAM TO PRESENT
(RY $M)

MAJOR CONTRACTS	POP 81-1*	POP 82-2**	PRE POP 83-2***
FAINT OBJECT SPECTROGRAPH (FOS)	28.1	31.5	39.5
HIGH RESOLUTION SPECTROGRAPH (HRS)	29.0	30.8	39.1
HIGH SPEED PHOTOMETER (HSP)	5.5	6.1	7.6
WIDE FIELD/PLANETARY CAMERA (WF/PC)	43.7	46.9	57.8
SCIENCE INSTRUMENT COMMAND AND DATA HANDLING (SI C&DH)	32.1	39.2	45.7
TOTAL POP****	174.5	179.2	224.8
LRD (LAUNCH READINESS DATE)	1/85	1ST QUARTER 1985	6/86

*INCORPORATED REPHASED PROGRAM SUBMITTED APRIL 1981 (BEFORE)

**LAST OFFICIAL POP SUBMITTED TO NASA HEADQUARTERS - JULY 1982

***POP 83-2 TO BE SUBMITTED JULY 1983

****INCLUDES ABOVE PLUS OVERGUIDES, SCIENCE TEAM, PROGRAM SUPPORT, IMS, CONTINGENCY

Mr. VOLKMER. I have some questions here that I had for Dr. Lucas. I believe it was on the faint object spectrograph. I believe you did talk about replacing the——

Dr. HINNERS. Yes, we are changing the detector on that.

Mr. VOLKMER. Why are the two that we are going to replace them with, the spares, going to do any better than the two that are in there now?

Dr. HINNERS. We understand the reason for the degradation. The degradation had nothing to do on that red detector with the tube itself. It was related to a power supply which, in testing the instrument, was supposed to be at zero when the automated system was checking it out. It turns out the power supply to the tube was not at zero but that there was a voltage on that tube. It was exposed to light during the testing, and that is what did the tube in. That was a procedural error in the development testing.

Mr. VOLKMER. In other words, it was an occurrence within the tests that caused the degradation?

Dr. HINNERS. That is correct. There was nothing wrong with the tube itself. That is in contrast to the high-resolution spectrograph, where there was a basic problem in the tube itself and we now know what will fix the tube.

Mr. VOLKMER. You have to make a new tube there.

Dr. HINNERS. A new coating for that tube, right, which has been tested and works.

Mr. VOLKMER. On reprograming, what is the impact on the science institute and ground management systems of the current plans to reprogram funds from these activities to development?

Dr. HINNERS. Some of the funding being reprogramed from operations, I believe, will have little impact on the operations per se because with the stretchout of development much of the operations indeed will not occur until after, of course, you launch. So, there is some give and take there that is no immediate problem.

The most immediate problem I see is indeed on the science operations ground systems software, which I talked about before. We are working that with Marshall and looking at the whole thing because they share our concern, as does headquarters, I think it is just a matter of analyzing it to be sure we understand what risks we are taking and what the real situation is.

Mr. VOLKMER. I am sure you want to make sure and we want to make sure that the ground system and the Science Institute will be in place when the space telescope is launched.

Dr. HINNERS. Absolutely. We have been burned too often in the past by late ground software.

Mr. VOLKMER. What is the current runout cost estimate for the space telescope operations budget?

Dr. HINNERS. This sounds like a Proxmire question because if it all works, we will work this thing for decades. I wouldn't want to inflate that, but the runout of our fiscal year 1984 budget assumed a level through 1988 of approximately.

Mr. VOLKMER. Annually or total?

Dr. HINNERS. Total, all years through 1989.

Mr. VOLKMER. That will be for total operations?

Dr. HINNERS. Right, through 1989; however, I hope that we will get many decades of operation of the space telescope, so we don't have a defined runout of funding.

Mr. VOLKMER. That is approximately 3 years of actual use, then?

Dr. HINNERS. That is correct.

Mr. VOLKMER. But we are anticipating that we will use it for longer than that?

Dr. HINNERS. Absolutely, hopefully decades.

Mr. VOLKMER. Will you say it is going to cost us $25 million a year for operations?

Dr. HINNERS. Our current assessment is approximately $40 million per year in the outyears for all operations activities.

Mr. VOLKMER. Does that include the institute?

Dr. HINNERS. Yes, that includes the institute.

Mr. VOLKMER. What is your biggest challenge that you see in the development of the space telescope for Goddard activities?

Dr. HINNERS. For Goddard there are two challenges. One is successfully completing the testing that is now going on and will go on through next summer with the instruments. We are just getting to the point where the instruments will show us what their problems are, if they have any. We have started to pick up the detector problems, so this is the period which one finds that kind of problem.

We are prepared to cope with some number of those, as we do in any standard development. The other has to come down to getting a total ground system playing together as one unit. We are giving a lot of extra attention to that.

Mr. VOLKMER. In your statement you note that a March design review pointed out some weaknesses in the automated science planning and scheduling approach.

Dr. HINNERS. That is correct.

Mr. VOLKMER. Can you elaborate on that a little bit?

Dr. HINNERS. That is part of what has been called the SOGS, which you are familiar with. At that review there were weaknesses pointed out in the development of the ground software. As an example, that system, as currently designed, is highly automated to do scheduling. If you get a sudden target such as recently happened, where a comet came in, and you wanted to look at something, it turned out——

Mr. VOLKMER. That you hadn't anticipated.

Dr. HINNERS. Right. It would have been very difficult to get into the system to do, let me call it, manual targeting. So, the system is being redesigned to give it more flexibility. In a sense, it was overautomated. That is an example of the kind of problem that comes up.

Our concern over the science operations ground system is sufficient that we did set up last month, in May, a special team under John Roeder at Goddard, including Institute people, to take a detailed technical look at the SOGS. They should be reporting back to me later this week or early next week on their findings.

Mr. VOLKMER. I have no further questions. Thank you very much, Dr. Hinners. We appreciate your letting Dr. Giacconi go ahead.

Dr. HINNERS. You are quite welcome. Thank you for the opportunity.

Mr. VOLKMER. The subcommittee will adjourn until Thursday at 2 for a continuation of the hearings.

[Whereupon, at 4:50 p.m., the subcommittee adjourned, to reconvene at 2 p.m., Thursday, June 16, 1983.]

SPACE TELESCOPE COST, SCHEDULE AND PERFORMANCE

THURSDAY, JUNE 16, 1983

House of Representatives,
Committee on Science and Technology,
Subcommittee on Space Science and Applications,
Washington, D.C.

The subcommittee met, pursuant to notice, at 2:12 p.m., in room 2325, Rayburn House Office Building, Hon. Harold L. Volkmer (chairman of the subcommittee) presiding.

Mr. Volkmer. The subcommittee will come to order.

Today the Subcommittee on Space Science and Applications is continuing our oversight review of the cost, schedule, and performance status of the space telescope program. We have previously heard testimony from the NASA cognizant field centers and the space telescope science institute.

This afternoon we will receive testimony from the space telescope associate contractors and from NASA headquarters.

Our first witnesses will be Robert Powell, vice president and general manager of the space systems division of Lockheed Missile and Space Co., accompanied by William F. Wright, vice president, NASA programs.

Our second witness will be Gaynor N. Kelley, executive vice president of Perkin Elmer Corp., accompanied by John D. Rehnberg, vice president and general manager of space sciences division.

Our final witness will be Hon. James Beggs, Administrator, National Aeronautics and Space Administration.

We will start with Mr. Powell. We have received a copy of your statement, as well as Mr. Wright's. Those will be made a part of the record. You may proceed by reviewing the statement in total or you may summarize, what you see fit.

STATEMENT OF ROBERT POWELL, VICE PRESIDENT AND GENERAL MANAGER, SPACE SYSTEMS DIVISION, LOCKHEED MISSILE AND SPACE CO., ACCOMPANIED BY WILLIAM F. WRIGHT, VICE PRESIDENT, NASA PROGRAMS, LOCKHEED MISSILE AND SPACE CO., AND BERT BULKIN, SPACE TELESCOPE PROGRAM MANAGER

Mr. Powell. Mr. Chairman and members of the subcommittee, it gives me a great deal of pleasure to be here before you this afternoon to brief you on our progress to date on the space telescope program.

The project has now reached a significant phase wherein the detail design for all of the elements of the program have been essentially completed, interfaces have been established, development testing is essentially complete, and we now enter into the manufacturing test and verification phase.

In addition, detail requirements have been reflected in all of the associate contractor's space telescope hardware specifications and are the basis for present hardware fabrication and acceptance testing.

One-third of the support systems module equipments have been completely fabricated, qualified, and acceptance tested; the other two-thirds are in the final fabrication and test phase and will support the start of the SSM testing by the middle of next year. In addition, significant improvements have been made in the flight gyros and reaction wheels which will insure meeting the space telescope critical pointing performance and image stability requirements. We expect to deliver our hardware and software on schedule and be ready for integrating the optical telescope assembly and the scientific instruments when they are shipped to us. Our new integration and test facility became ready for use this past January.

Today we will briefly summarize for you the cost, schedule and performance aspects relative to the Lockheed Missile and Space Co.'s development activities for the space telescope program.

Accompanying me today is Bill Wright, vice president, NASA programs at Lockheed Missile and Space Co., who will present to you an overview of our progress, accomplishments, and challenges, together with our future plans. In addition, Bert Bulkin, space telescope program manager, will accompany Bill during the question and answer period following our formal statement.

Thank you, sir.

Mr. VOLKMER. Thank you.

You may proceed, Mr. Wright.

Mr. WRIGHT. Mr. Chairman and members of the committee, I am delighted to be here again to discuss with you the overall status of our part in this very important and vital program. My statement today will highlight and summarize briefly the highlights of our accomplishments, especially the previous year; current technical and schedule status; technical problems that have developed and their resolution; and a description and status of our very important new facility. I will also mention some of our major challenges and risks as we see them. In addition, I will conclude with a review of our management realignments that we have incorporated and an overview of our funding picture.

The first chart, on your left, shows an artist's conception of the space telescope. It truly is an international astronomical observatory consisting of a 2.4-meter optical telescope which will be placed in a nominal 320 nautical mile orbit and will be launched by the space shuttle in 1986. It weighs approximately 12 tons. It is 14 feet in diameter and 43 feet long. It is the first shuttle payload which is designed with the shuttle in mind; that is, the shuttle crew will conduct the initial deployment, perform contingency and routine maintenance, and participate in retrieval and return to earth.

The next chart illustrates the total ST system encompassing what we consider all the major elements of the system. There are five major elements; namely, the ST observatory, which is the space telescope itself; the space shuttle; the tracking and data relay satellites; the Operations Control Center at Goddard; and, of course, the Science Institute, at which I had the privilege of attending yesterday's dedication.

The ST observatory has three major modules; namely, the optical telescope assembly, the scientific instruments, and the support systems module.

Our responsibility as part of this overall program includes four basic areas; namely, the ST systems engineering support and which I will discuss in more detail later; insuring system capability among all the ST system elements; the design and development of the support systems module, which includes incorporating the European-supplied solar arrays. In addition, we will perform the ST integration, including the assembly, test and verification at Sunnyvale in our new facility complex, and finally, an important function in supporting the mission operations.

The next chart illustrates the overall schedule plan now being utilized by LMSC. It shows the key delivery dates of all the associate contractor hardware to Lockheed for subsequent functional and environmental testing of the entire ST observatory. Lockheed is tracking on schedule to this plan, and we are confident that the subsequent milestones can be met for the downstream hardware fabrication and assembly/test activities for both the support system module as well as the space telescope.

The key dates in our downstream planning for delivery of associate contractor hardware to Lockheed in preparation for assembly and testing the entire space telescope are shown on the chart: the European-supplied solar array in mid-1984, the scientific instruments and the optical telescope assembly in July and November 1984, respectively, leading to the start of the space telescope testing in the first quarter of 1985; a shipment to the Kennedy Space Center in February 1986 and launching in June of 1986. Key to this new plan that has been incorporated is the additional development tests, the support systems module equipment section integration with scientific instruments prior to the arrival of the optical telescope assembly, and an expanded space telescope assembly and verification program.

Another key milestone in this new plan is we have added to the program a detailed hardware/software integration program which has already started. This program sequentially incorporates portions of our data management subsystem, the pointing control subsystem, and the flight software. This program will afford early visibility into the compatibility of these critical elements. This facility will remain active through April or May of 1984. The next chart shows the initial setup utilizing the flight model DF-224 Rockwell Digital Computer and all the peripherals.

Of particular significance in this next chart is the summary of the accomplishments over the past year. Improved gyro performance has been realized based upon our test results at Holloman Air Force Base in New Mexico. That indicated to us that the shroud which has been incorporated to reduce the noise contribution within the pointing and control system results in a much quieter gyro, thereby contributing significantly to the attainment of the stringent pointing and control requirements. Tests on two engineering gyros and flight gyros substantiate and verify that the performance, exceeds the power spectral density specifications by five times, thereby reducing the average noise by more than a factor of two.

In addition, the reaction wheels, which provide the ST maneuvering and pointing capability, have been retrofitted to improve the induced vibration characteristics by a factor of three, thereby improving pointing and control performance. This improvement was made possible by incorporating low noise bearings and a stiffened mounting structure, which gave us the specified characteristics desired.

Major milestones during this period have been the completion and delivery of the Perkin-Elmer equipment section, which houses much of the Perkin-Elmer electronic equipment, and the completion of the primary structures for the support systems module light shield, forward shell, and equipment section. The aft shroud will be completed on July 8, and is on schedule.

Significant subcontract flight hardware was delivered during this period. In addition, over 26 individual items of interface equipment have been delivered to our associate contractors.

The support systems module major equipment hardware is shown on the following chart. This chart illustrates the location of the hardware within the SSM equipment section which contains most of the electronics and control hardware. The SSM is divided into four major sections; namely, the light shield which provides stray light protection for the optical telescope assembly and the forward shell which is light-tight and supports the solar array, high gain antenna mounting, and carries the trunnion fittings which interface with the shuttle orbiter.

The equipment section, which, is highlighted on this chart highlighted, has most of the data management equipment, electrical power, pointing control equipment and instrumentation and communication electronics.

The fixed head star trackers and rate gyro assembly are mounted on the focal plane to assure overall accuracy.

The light-tight aft shroud, which has access doors for orbital replacement capability for the scientific instruments, also provides the thermal protection for the scientific instruments and thermal stability. It also provides the structural fittings for erecting the ST while in the orbiter bay.

Subcontract flight equipments already delivered are the computers, rotary drives, fixed head star trackers, the first SSA transmitter, tape recorder, retrieval gryo assembly, oscillator, and other miscellaneous equipment. Out of the total complement of 98 individual equipments in the support systems module, approximately one-third or 33 have been completed and are in storage awaiting installation into the support systems module. The remainder are in the final fabrication and test phase. All hardware fabrication and test activites will support the start of our SSM equipment section testing in mid-1984.

The next chart shows the completed optical telescope assembly equipment section, which I referred to earlier, on its dolly as it was delivered to Perkin-Elmer in September of last year.

The following chart shows the equipment section mockup which has been used in providing a basis for installing our flight electronic cable installations. The fabrication of flight wire harnesses in this mockup provides a low cost alternate to extensive documentation or, as an alternate, extremely expensive three-dimensional form boards that would be required in the fabrication of these very large harnesses, which approximate 20,000 wires. This activity has commenced and is on schedule, and we hope to complete by July 1983, at which time the wire harnesses will be transferred and installed into the flight equipment section.

The next chart shows the 14-foot-diameter flight SSM equipment section with a portion of the bay doors installed. This 5-foot structure was completed on schedule with zero defects. The total weight of the total equipment section is approximately 6,000 pounds.

The next chart shows the fabrication completion of the light shield primary structure.

The next chart shows the light shield, which is also 10 feet in diameter and 13 feet in length and weighs about 500 pounds.

The next chart is the aft shroud, which is 14 feet in diameter, 12 feet long, and weighs approximately 1,350 pounds.

The next chart shows the automated test software computer facility located in this new vertical assembly and test facility that has just been in operation in Sunnyvale for the past 2 months. Utilization of this facility continues the Lockheed experience of minimizing system test costs by providing the capabilities to prevalidate all our test procedures, via simulation, before actual hardware testing commences. This central computer consists of two Digital Equipment Corp. computers with standard peripherals.

This facility will be used for SSM flight software development and verification, test software development, and engineering data base development.

The following chart is a new building that I referred to earlier. It is constructed and funded by Lockheed, which will serve as an SSM and ST final assembly and test facility at our Sunnyvale, Calif., complex. This facility has been completed and activated and is adjacent to our existing environmental test facilities. This new facility consists not only of one of the world's largest laminar flow cleanrooms for spacecraft integration, but also the necessary support facilities to house support equipment and people for all of the people both here and in Europe that will be supporting the ST testing.

The cleanroom is 50 feet wide, 120 feet long, and 85 feet high, capable of meeting class A 10,000 requirements using a horizontal laminar flow system. A 20-ton radio-controlled bridge crane with a 76-foot hook height will service this cleanroom.

The contiguous support facility contains 47,000 square feet of desk and board space and sufficient space for the automated test software equipment that I referred to earlier. The new cleanroom opens within the same building housing the spacecraft vertical acoustic test chamber and the horizontal thermal vacuum test chamber.

This next chart shows a view of the facility from the second floor observation window when the facility was certified for 10,000 class cleanroom, and the following shows the construction of the vertical integration stand which will support the ST assembly and verification program by placing the ST in a vertical stacking position for testing and replacement of hardware, if necessary.

During the past year we have encountered some problems, especially at the beginning of the fiscal year, in the area of structural tooling and subassembly fabrication and also replacement of the S311 wire in the equipment section.

In addition, our data management unit, which is a part of our data management system, and our digital interface unit experienced some difficulties in the transposition from the engineering models to the flight units. The tooling effort was higher than anticipated because of the extremely close tolerance of 5,000th of an inch required, on these large structures.

Structural subassemblies followed the same problem because of these close tolerances. These problems, I am happy to say, are behind us now, and the major structures have completed, as shown in the previous charts. They are ahead of schedule in with zero defects.

The S311 wire, which you saw in a previous chart, originally was installed in the mockup as flight harnesses and had to be replaced because of the flaking of the blue tracer on the wire which have caused contamination. This wire definitely had to be removed, new harnesses made, and then reinstalled in the mockup. This was also accomplished, and we have established workarounds to factor this late delivery in our current plan.

During this same time period we consciously put into the program a preproduction model of our data management unit. The complexity of this electronic box warranted this action. It serves as the heart of the entire ST vehicle since it interfaces with all functional equipment, including the digital computers, and contains over 60 printed wiring assembly boards containing over 6,000 electronic piece parts, and they in turn are connected by a matrix board containing 7,000 wires. The preproduction unit will serve to maintain the key milestones stated previously at the start of our hardware/software integration activity and will allow us to check out the automated test stations together with the software.

Measures have been taken to reduce the flight software memory utilized in the flight computer to assure a 20-percent reserve available at launch to handle unexpected contingencies. This is being aggressively pursued to avoid changes to our data management unit to handle additional memory.

I feel these problems are behind us now and that we are tracking to our schedule plan.

In terms of the future challenges and schedule risks, our near term challenge deals with the start of our hardware/software integration activity. This is the first time we will have physically and functionally integrated flight hardware, test hardware, and flight software. These hardware items include our flight Rockwell digital computer, the data interface and data management units, and simulating our pointing and control system, together with the ground computer. Our technical challenge in this regard is the physical compatibility of these hardware, their functional compatibility, and the ability of the flight software to execute its instructions, because our experience in other programs has shown that in many cases software is a very critical and time-consuming activity, and oftentimes can pace the whole program. Therefore, we place a great deal of emphasis on this activity.

The second area of challenge will be the successful deployment of the high gain antenna pointing system that can support the communication link requirements without inducing unacceptable vehicle disturbances, thereby adversely affecting vehicle pointing stability. This will require a system with the correct balance of antenna stability, pointing accuracy, and reactive torques. Testing is underway to define the explicit requirements for optimum performance which hopefully, can be accomplished with very few changes that would affect our cost.

The third major challenge is to assure that an accurate data base is established for all project elements and procedural inputs are timely to support this very important, forthcoming scientific instrument support systems module integration and the start of ST assembly and verification.

The fourth challenge, as we see it, that has an effect on cost and schedule is the availability of spares. NASA is taking the corrective action with us to order additional spares. However, because of the timing of that aspect, we will only have the spares in time for the ST assembly and verification time period. For the SSM testing even though we will have spare cards for electronics, we feel that the spares are deficient. However, this is compensated to a certain extent by the increased test time that has been added to the program not only for the SSM, but for the ST.

It still remains, however, that the major scheduling cost risk still lies in the ST assembly and verification phase, when all the elements of the program, both hardware and software, come together, including the mission operations ground system.

In recognition of the stated need for added emphasis and greater depth in the systems engineering, we at Lockheed have established a new and separate organization. This organization reports directly to me and will work in direct support of NASA Marshall Space Flight Center, which has taken a similar step in their structure. It is headed by Tom Harvey, who was previously Deputy Program Manager of the Support Systems Module activity and is now Director of space telescope Systems Engineering.

We have increased the staff from 25 to 70 people and will further increase to approximately like 100 by the end of this fiscal year. The objective of this organization is to provide indepth penetration of all the modules' technical status and to integrate them into the system which accomplishes the science objectives. With primary emphasis on the forthcoming ST test and verification phase, they will maintain and update technical and test requirements, assure proper verification and compliance with them, audit electronics and hardware interface designs, as well as integrating the very critical pointing control and fine guidance system into an accurate, stable, and operational system.

Our cumulative costs expended through May are within $1 million of our plan. While we are slightly in an overrun position, we are confident that we will meet our funding guideline which we have signed up for with Marshall for the remainder of this fiscal year.

We are presently assessing the compatibility of the funding plan, the added scope that has been incorporated to reduce downstream risk, together with the schedule plan that I have previously shown. We expect to finalize this review with Marshall within the next 2 months.

To summarize, gentlemen, we are tracking to our new plan within our projected costs and we are performing well. We are looking forward to the next phase of the program in completing fabrication of flight hardware, assembling the SSM and conducting the all-up ST environmental testing in Sunnyvale, leading to a fully tested ST to be delivered to Kennedy, and hopefully launched in June 1986.

That concludes my prepared remarks, Mr. Chairman. I am available for questions.

[The prepared statements, plus answers to questions asked of Robert Powell and William F. Wright follow:]

STATEMENT OF

MR. ROBERT M. POWELL
VICE PRESIDENT AND ASST. GENERAL MANAGER
SPACE SYSTEMS DIVISION

BEFORE THE

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

of the

COMMITTEE ON SCIENCE AND TECHNOLOGY
U. S. HOUSE OF REPRESENTATIVES

Gentlemen, it gives me a great deal of pleasure to be here before your committee to brief you on our progress to date on the Space Telescope Program.

The project has now reached a significant phase wherein the detailed design for all the elements of the program have been essentially completed, interfaces have been established, development testing is essentially complete, and we now enter into the manufacturing, test and verification phase. In addition, detailed requirements have been reflected in all of the associate contractor's Space Telescope hardware specifications and are the basis for present hardware fabrication and acceptance testing.

One-third of the Support Systems Module (SSM) equipments have been completely fabricated, qualified, and acceptance tested; the other two-thirds are in the final fabrication and test phase and will support the start of the SSM testing by the middle of next year. In addition, significant improvements have been made in the Flight Gyros and Reaction Wheels which will insure meeting the Space Telescope critical pointing performance and image stability requirements. We expect to deliver our hardware and software on schedule and be ready for integrating the Optical Telescope Assembly and the Scientific Instruments when they are shipped to us.

We are very proud to be part of the Government/Industry Space Telescope team and certainly feel that the Space Telescope represents a major step in astronomy and will lead to a quantum jump in our fundamental understanding of our universe and perhaps lead to a better understanding of the environment in which we live. I expect that, despite the optimism thus far by the scientific community, we have, in fact, underestimated the contribution that this program will ultimately make to our knowledge of astronomy and astrophysics. Much remains to be done but when it is accomplished, I think we shall have a truly magnificent scientific facility on orbit.

Today we will briefly summarize for you the cost, schedule and performance aspects relative to the Lockheed Missiles and Space Company's development activities for the Space Telescope Program. Accompanying me today is Bill Wright, Vice President, NASA Programs at Lockheed Missiles and Space Company, who will present to you an overview of our progress, accomplishments, and challenges, together with our future plans. In addition, Bert Bulkin, Space Telescope Program Manager, will accompany Bill during the question and answer period following our formal statement.

STATEMENT OF

MR. WILLIAM F. WRIGHT
VICE PRESIDENT, NASA PROGRAMS
LOCKHEED MISSILES & SPACE CO., INC.

BEFORE THE

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

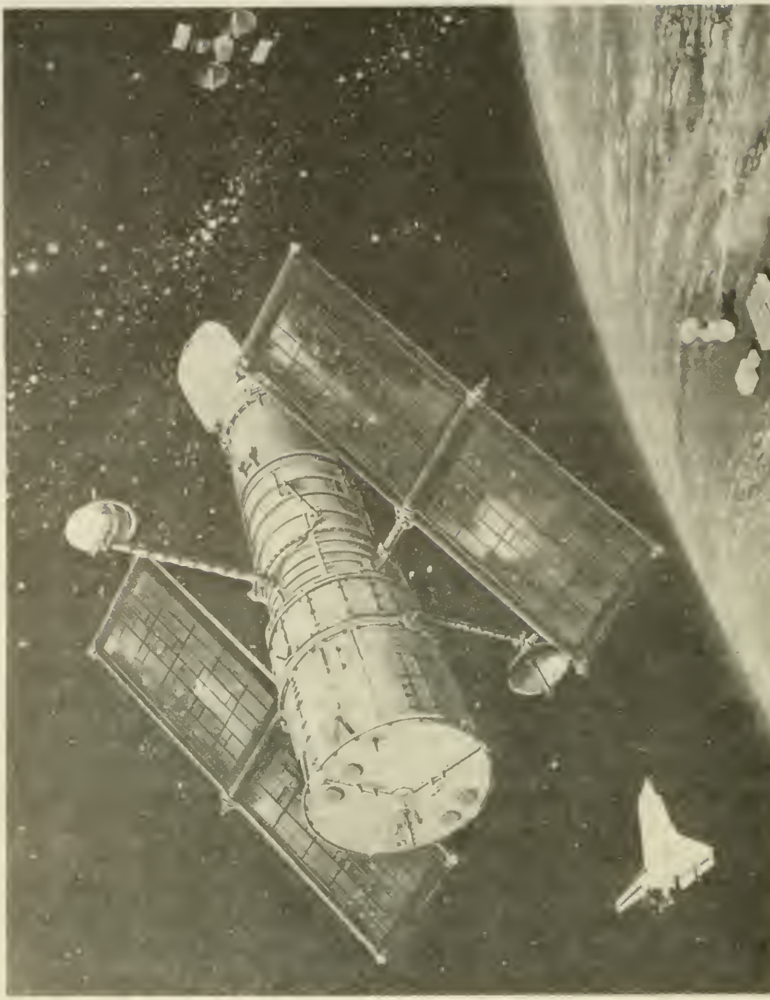
of the

COMMITTEE ON SCIENCE AND TECHNOLOGY
U. S. HOUSE OF REPRESENTATIVES

Gentlemen, I am delighted to be here again to discuss with you the overall status of the Space Telescope Program. My statement today will cover the following: Highlights of our accomplishments to date; current technical and schedule status; technical problems that have developed and their resolution; a description and status of our new facility; and our major challenges together with our assessment of future technical and schedule risks. In addition, I will conclude with a review of our management realignments and an overview of our cost and funding plan.

Figure 1 is an artist's conception of the Space Telescope (ST) as it would appear in orbit. The Space Telescope is an International Astronomical Observatory consisting of a 2.4 meter optical telescope which will be placed in a nominal 320 nautical mile orbit by the Space Shuttle in 1986. It weighs approximately 24,000 pounds; it is 14 feet in diameter and 43 feet long. This will be the first payload for the Shuttle which will have been designed with the Shuttle in mind whereby the Shuttle crew will conduct the initial deployment, perform contingency and routine maintenance, and participate in retrieval and return to earth.

Figure 2 illustrates the total ST system encompassing all the major elements of that system. There are five major elements, namely, the ST Observatory, the Space Shuttle, the Tracking and Data Relay Satellites (TDRSS), the ST Operations Control Center, and the Science Institute. The ST Observatory has three major modules, namely the Optical Telescope Assembly (OTA), the Scientific Instruments (SI), and the Support Systems Module (SSM).



8092A

Figure 1

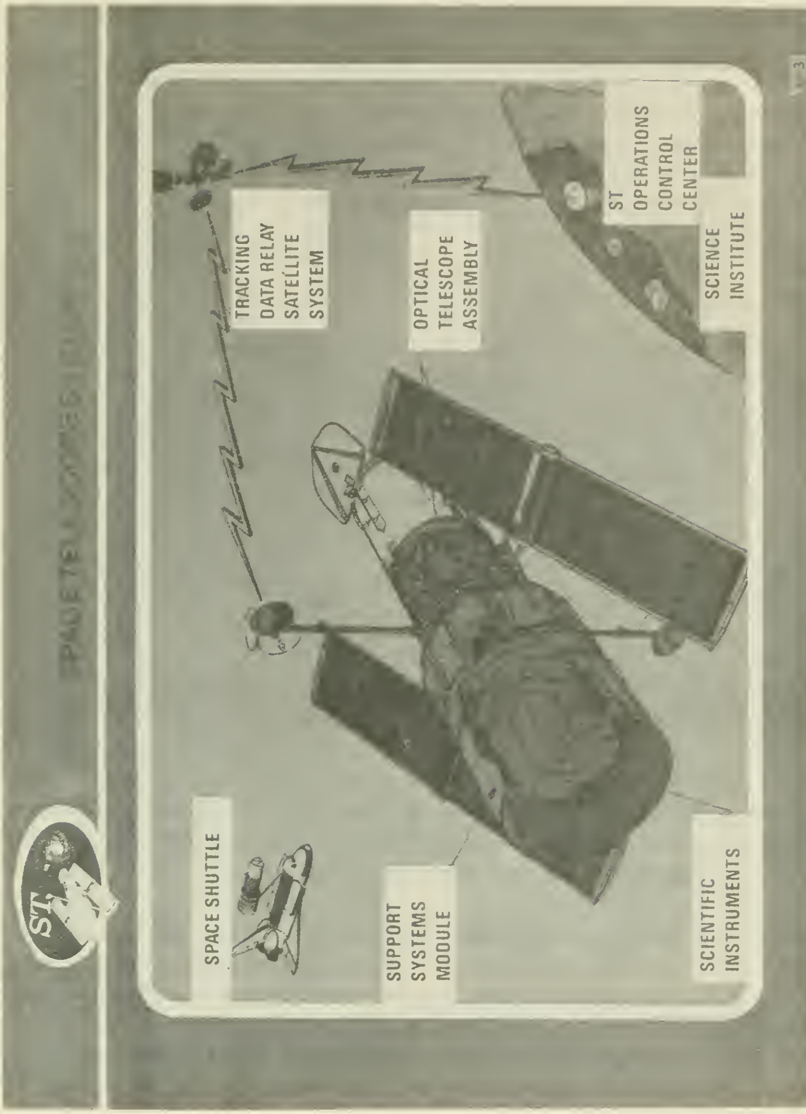

ST
SPACE SHUTTLE
SUPPORT SYSTEMS MODULE
SCIENTIFIC INSTRUMENTS
TRACKING DATA RELAY SATELLITE SYSTEM
OPTICAL TELESCOPE ASSEMBLY
ST OPERATIONS CONTROL CENTER
SCIENCE INSTITUTE

Figure 2

Lockheed's responsibility as a part of the overall ST project includes four basic areas, namely ST Systems Engineering Support which insures system compatibility among all the ST system elements; the Design and Development of the Support Systems Module, which includes integrating the European-supplied Solar Arrays; ST integration including the assembly, test and verification of the complete ST Observatory; and finally, Mission Operations Support which includes launch preparation, checkout, orbital verification, and on-going mission operations.

Technical and Schedule Status

Figure 3 illustrates the overall schedule plan currently being assessed by LMSC. It shows the key delivery dates of all the associate contractor hardware to Lockheed for subsequent functional and environmental testing of the entire ST Observatory. Lockheed is tracking on schedule to this plan, and we are confident that the subsequent milestones can be met for the downstream hardware fabrication and assembly/test activities for both the SSM and the ST. The key dates in our downstream planning for delivery of associate contractor hardware to Lockheed in preparation for assembly and testing of the entire Space Telescope are as follows: the European-supplied Solar Array in mid-1984, the Scientific Instruments and the Optical Telescope Assembly in July and November 1984 respectively. Other key dates are: initiation of SSM assembly in December 1983, start SSM test and subsequent SSM/SI test in the second half of 1984, initiate ST assembly in December 1984, and start ST testing in the first quarter of 1985, leading to the shipment of ST to Kennedy Space Center in February 1986 in preparation for launch in June 1986. Key to this plan is the incorporation of additional development tests, SSM Equipment Section Integration with Scientific Instruments prior to the arrival of the OTA, and an expanded ST Assembly and Verification program.

Another key schedule milestone that has been added to the Program is the initiation of our Hardware/Software integration program which started 1 June 1983. This program sequentially incorporates portions of the Data Management Subsystem, the Pointing Control Subsystem, and the Flight Software. This program will afford early visibility into the compatibility of these critical elements ahead of the initiation of Support Systems Module Equipment Section tests.

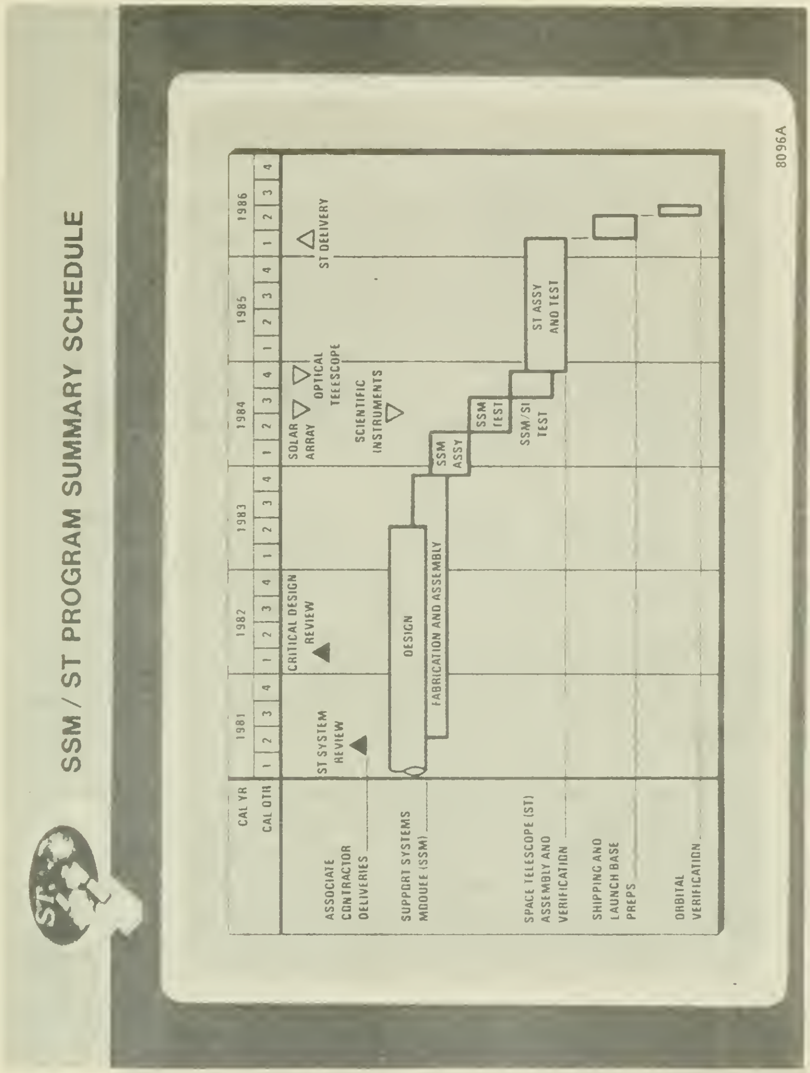

SSM / ST PROGRAM SUMMARY SCHEDULE
CAL YR
CAL QTR
1981
1982
1983
1984
1985
1986
ASSOCIATE CONTRACTOR DELIVERIES
SUPPORT SYSTEMS MODULE (SSM)
SPACE TELESCOPE (ST) ASSEMBLY AND VERIFICATION
SHIPPING AND LAUNCH BASE PREPS
ORBITAL VERIFICATION
ST SYSTEM REVIEW
CRITICAL DESIGN REVIEW
SOLAR ARRAY
OPTICAL TELESCOPE
SCIENTIFIC INSTRUMENTS
ST DELIVERY
DESIGN
FABRICATION AND ASSEMBLY
SSM ASSY
SSM TEST
SSM/SI TEST
ST ASSY AND TEST
8096A

Figure 3

This facility will remain active from 1 June 1983 through April 1984. Figure 4 shows initial setup utilizing the Engineering Model DF-224 computer and its peripherals.

Figure 5 lists the major schedule accomplishments of the past year.

Of particular significance was the validation of the improved gyro performance at Holloman Air Force Base, New Mexico. An improved Gyro has been developed utilizing a shroud to reduce the noise contribution within the Pointing and Control System resulting in a much quieter gyro and thereby contributing significantly to the attainment of the stringent Pointing and Control requirements. Tests on two engineering gyros and flight gyros substantiate the fact that gyro performance noise power spectral density is five times better than specified values. This reduces the average noise by more than a factor of 2.

In addition, the Reaction Wheels, which provide the ST maneuvering and pointing capability have been retrofitted to improve the induced vibration characteristics by a factor of 3, thereby improving pointing and control performance. This performance improvement was made possible by incorporating low noise bearings as well as a stiffened mounting structure. In addition, a more perceptive bearing test capability was developed permitting optimal bearing selection to obtain specific characteristics for minimum overall system vibration.

Major milestones during this period have been the completion and delivery of the Perkin-Elmer Equipment Section and the completion of the primary structures for the SSM Light Shield, Forward Shell and Equipment Section. The Aft Shroud completion is scheduled for 8 July 1983 and is on schedule. We incorporated a Data Management preproduction unit to assure its use in test equipment checkout as well as supporting the Hardware/Software integration activity ahead of the complete assembly and qualification of the flight unit and to allow early compatibility tests with the other major subsystem elements. Significant subcontract flight hardware was delivered during this period. In addition, over 26 individual items of interface


DF-224 COMPUTER AND TEST EQUIPMENT

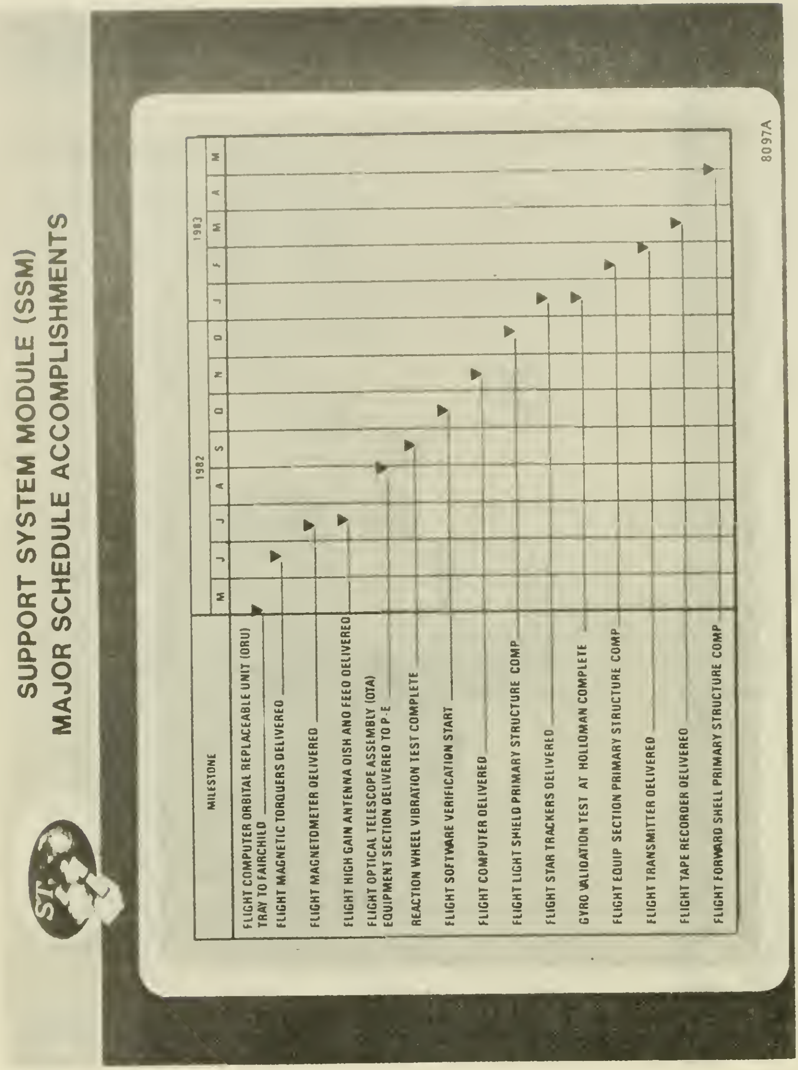

SUPPORT SYSTEM MODULE (SSM)
MAJOR SCHEDULE ACCOMPLISHMENTS
ST
MILESTONE
1982
1983
M J J A S O N D J F M A M
FLIGHT COMPUTER ORBITAL REPLACEABLE UNIT (ORU) TRAY TO FAIRCHILD
FLIGHT MAGNETIC TORQUERS DELIVERED
FLIGHT MAGNETOMETER DELIVERED
FLIGHT HIGH GAIN ANTENNA DISH AND FEED DELIVERED
FLIGHT OPTICAL TELESCOPE ASSEMBLY (OTA) EQUIPMENT SECTION DELIVERED TO P-E
REACTION WHEEL VIBRATION TEST COMPLETE
FLIGHT SOFTWARE VERIFICATION START
FLIGHT COMPUTER DELIVERED
FLIGHT LIGHT SHIELD PRIMARY STRUCTURE COMP
FLIGHT STAR TRACKERS DELIVERED
GYRO VALIDATION TEST AT HOLLOMAN COMPLETE
FLIGHT EQUIP SECTION PRIMARY STRUCTURE COMP
FLIGHT TRANSMITTER DELIVERED
FLIGHT TAPE RECORDER DELIVERED
FLIGHT FORWARD SHELL PRIMARY STRUCTURE COMP
8097A

Figure 5

equipment have been delivered to the SI contractors, Perkin-Elmer, IBM and British Aerospace to aid and assist their build and test activities for equipment which interfaces with the Support Systems Module.

The Support Systems Module (SSM) major equipment hardware is shown in Figure 6 illustrating the location of hardware within the SSM equipment section which contains most of the electronics and control hardware. The SSM is divided into four major sections; namely, the Light Shield which provides stray light protection for the OTA and the Forward Shell which is also light-tight and supports the solar array, high gain antenna mounting, and carries the trunnion fittings which interface with the Shuttle Orbiter. The Equipment Section houses most of the basic data management equipment, electrical power control equipment, certain pointing control equipment and instrumentation and communication electronics which are shown in the figure. The Fixed Head Star Trackers and Rate Gyro Assembly, critical components of the pointing and control system, are mounted on the Focal Plane to assure overall accuracy, and are also shown. The light-tight Aft Shroud, with its access doors for SI orbital replacement capability, also provides the thermal protection for the scientific instruments and provides thermal stability and isolation with the OTA. It also provides the structural fittings for erecting the ST while in the Orbiter bay. All of these flight hardware equipments have either been delivered or are in the final fabrication/qualification acceptance testing phase.

Subcontract flight equipments already delivered are the Computers from Rockwell International, Rotary Drives from Schaeffer Magnetics, the Transponders from Motorola, flight complement of Fixed Head Star Trackers from Ball Brothers, first SSA Transmitter from Cubic, first Tape Recorder from Odetics, Retrieval Mode Gyro Assembly from Northrop, Oscillator from Frequency Electronics, High Gain Antenna from General Electric, RF Circulator Switches from Electromagnetic Sciences, Umbilical Actuators from Sperry, and the RF Multiplexer Switches from Frequency Sources. Out of the total complement of 98 individual equipments in the SSM, 33 have been completed and are in storage awaiting installation into the SSM and 63 are in the final fabrication and test phase. All hardware fabrication and test activities will support the start of SSM equipment section testing in mid-1984.

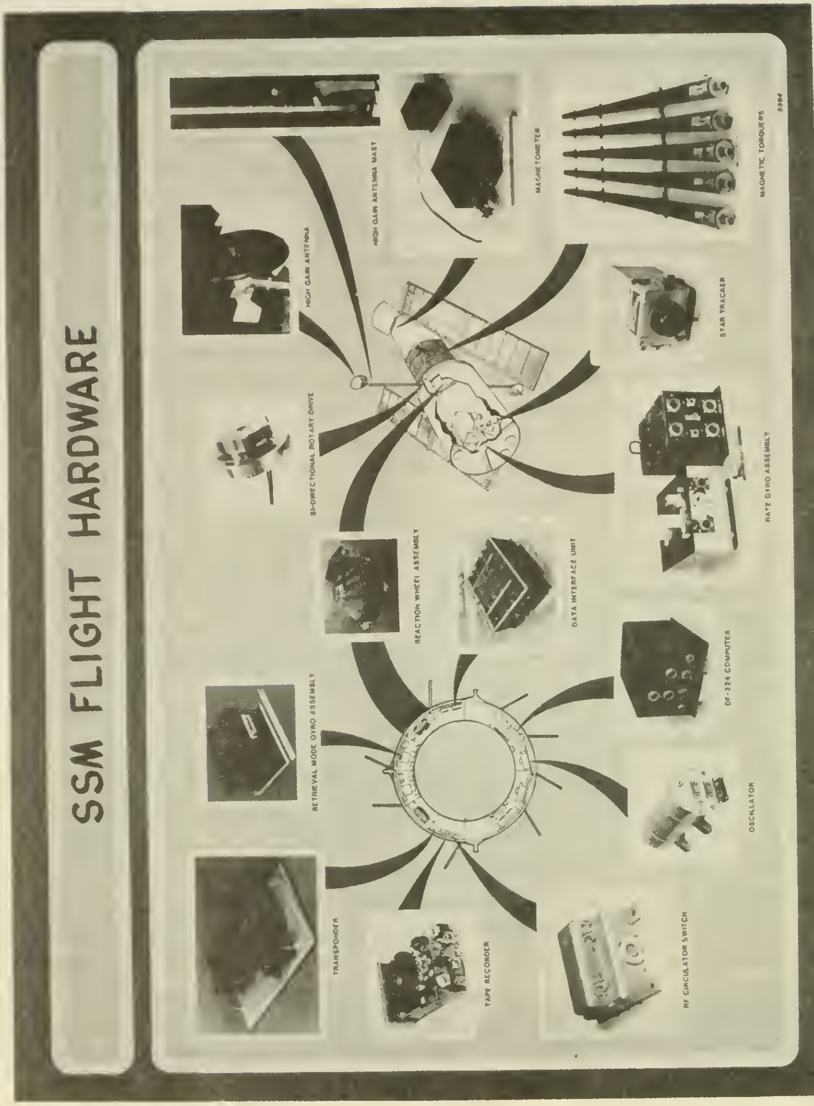

SSM FLIGHT HARDWARE
HIGH GAIN ANTENNA
HIGH GAIN ANTENNA MAST
MAGNETOMETER
MAGNETIC TORQUERS
BI-DIRECTIONAL ROTARY DRIVE
STAR TRACKER
RATE GYRO ASSEMBLY
REACTION WHEEL ASSEMBLY
DATA INTERFACE UNIT
RETRIEVAL MODE GYRO ASSEMBLY
DF-224 COMPUTER
OSCILLATOR
TRANSPONDER
TAPE RECORDER
RF CIRCULATOR SWITCH

Figure 6

Figure 7 shows the completed OTA Equipment Section and its dolly as it was delivered to Perkin-Elmer in September 1982.

Figure 8 shows the SSM Equipment Section mockup in more detail depicting the equipment that will provide the basis for the electronic cable installations. This approach was conceived by Lockheed; the fabrication of the flight wire harnesses provides an extremely low cost alternate to extensive documentation or, as an alternate, extremely expensive three dimensional form boards that would be required in the fabrication of these very large harnesses which contain over 20, 000 wires. This activity has commenced and is on schedule with estimated completion in July 1983 at which time the flight wire harnesses will be transferred and installed into the Flight Equipment Section.

Figure 9 shows the Flight 14-foot diameter SSM Equipment Section with a portion of the bay doors installed. The 5-foot long primary structure was completed on schedule with zero defects. The total weight of the equipment section with equipment installed is 5, 900 pounds.

Figures 10, 11 and 12 show the manufacturing status of the Light Shield, Forward Shell, and Aft Shroud. The Light Shield and Forward Shell are both 10 feet in diameter and 13 feet in length and weigh 500 pounds and 1, 000 pounds respectively. The Aft Shroud is 14 feet in diameter, 12 feet long and weighs 1, 350 pounds.

ST Vertical Assembly and Test Facility

Figure 13 is our Automated Test Software Computer facility located in the new ST Vertical Assembly and Test Facility. Utilization of this facility continues the Lockheed experience of minimizing system test costs (time) by providing the capabilities to prevalidate all test procedures, via simulation, before actual testing commences. Also derived from these simulations are predicted spacecraft responses to the test sequences, thus allowing all system parameters to be monitored in real time to pre-established limits. The central computer system consists of two Digital Equipment Corporation computers with standard peripherals which provide the pretest, real time and post-test processing. The

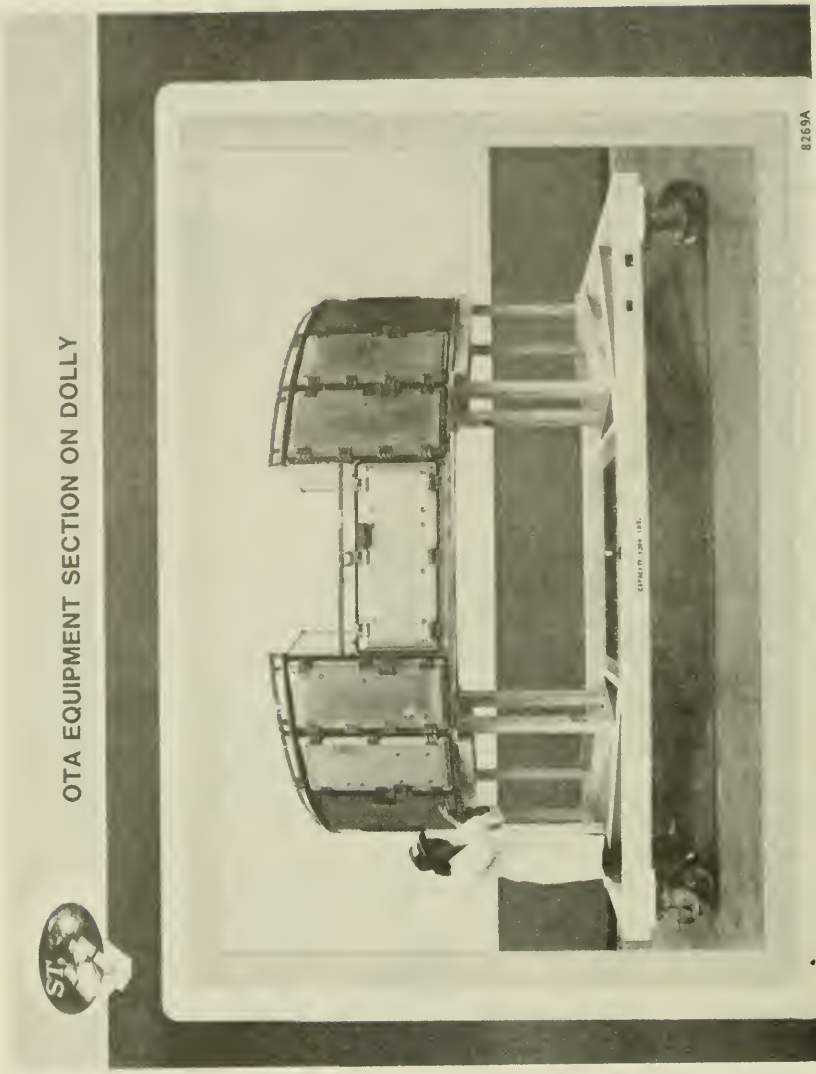
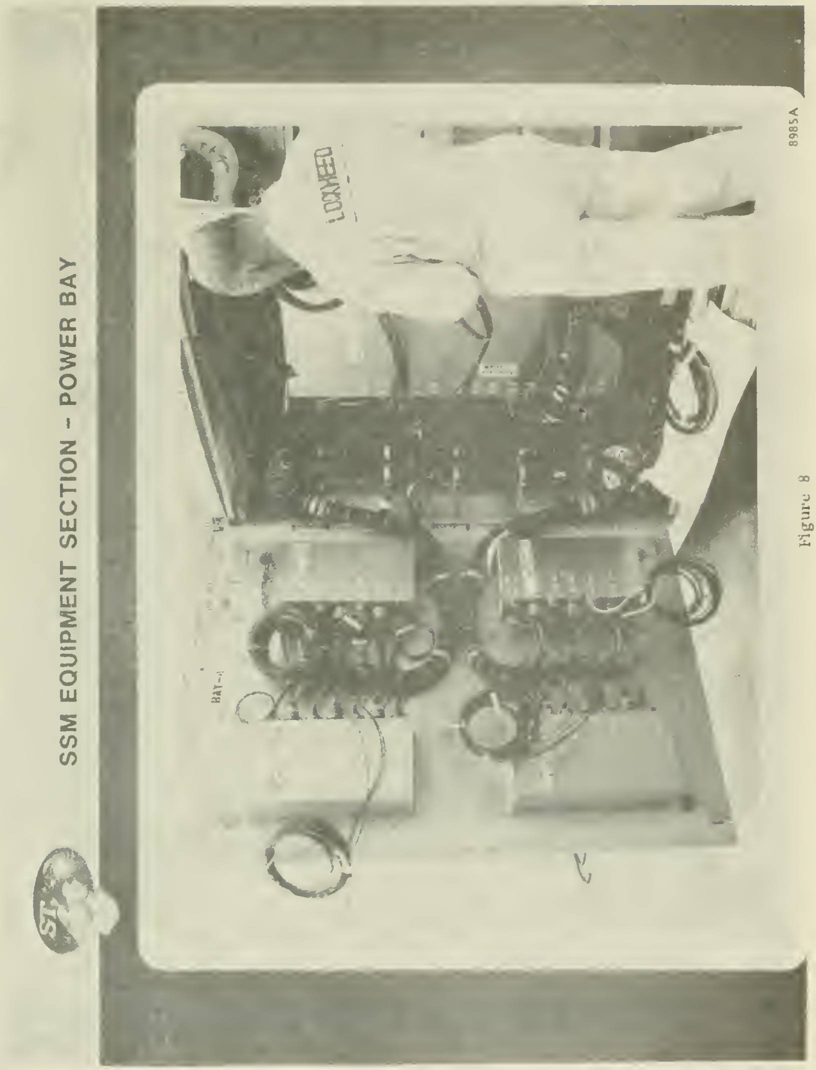


Figure 7


SSM EQUIPMENT SECTION – POWER BAY
LOCKHEED
8985A
Figure 8

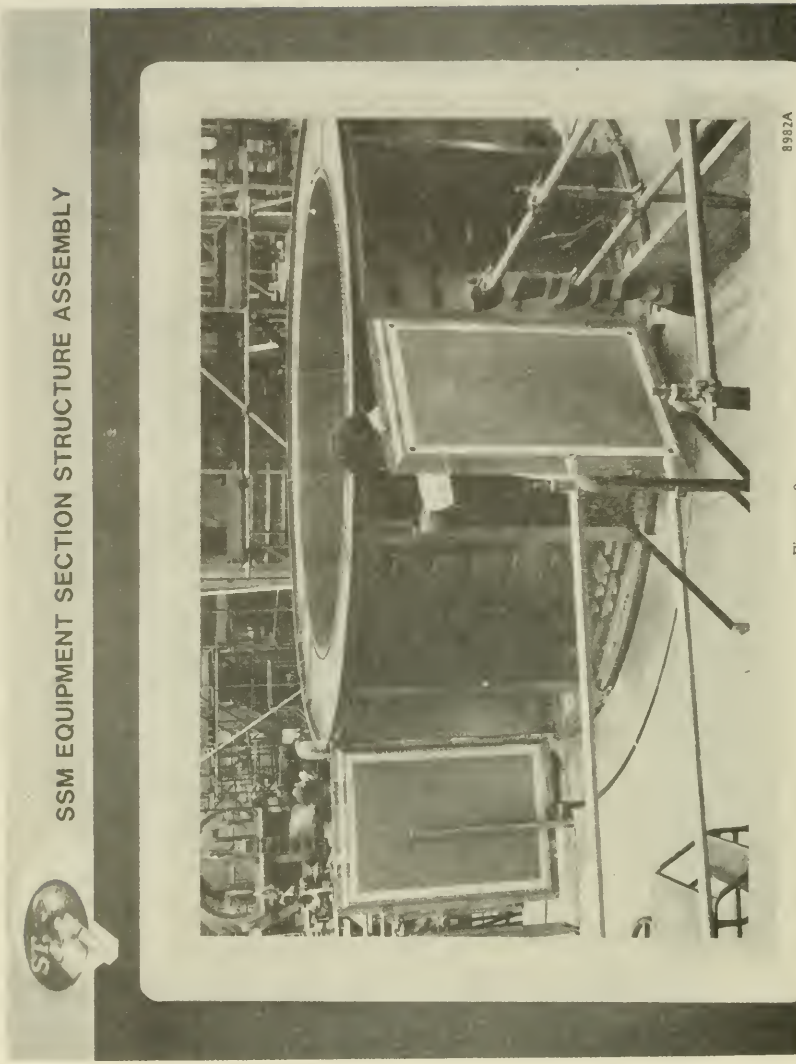


Figure 9

SSM LIGHT SHIELD
PRIMARY STRUCTURAL ASSEMBLY

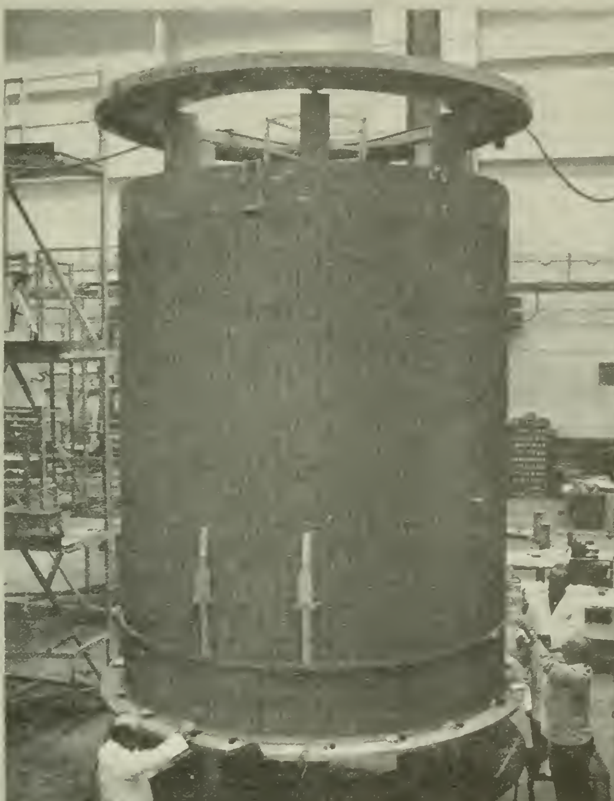


Figure 10

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SSM FORWARD SHELL PRIMARY STRUCTURE

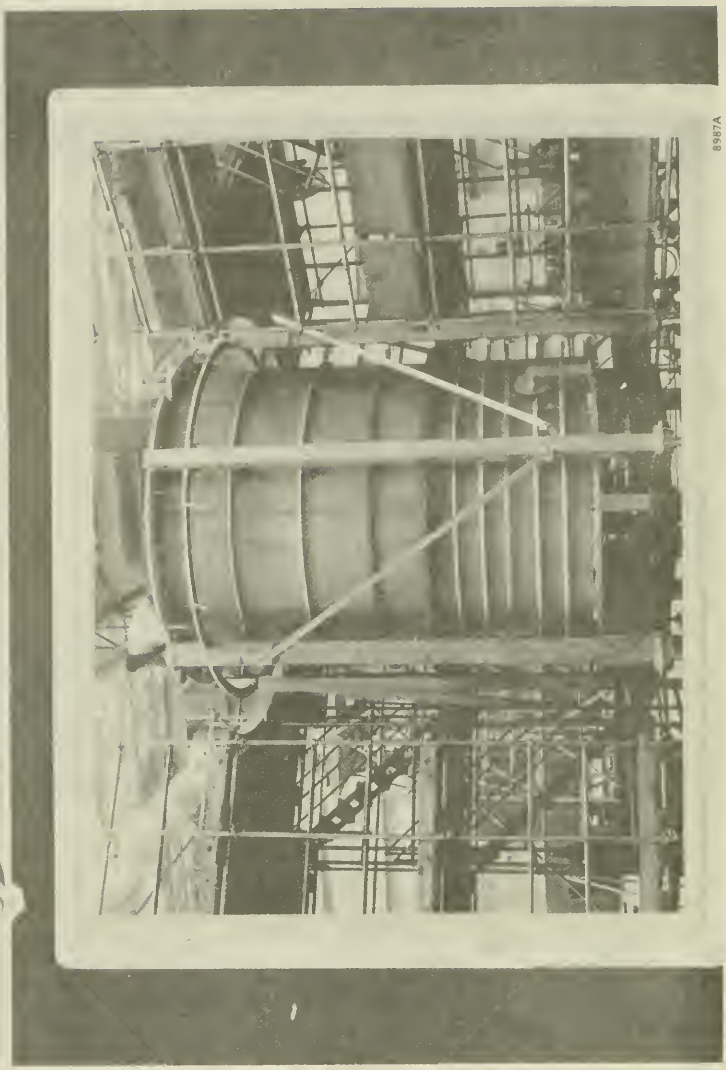

Figure 11

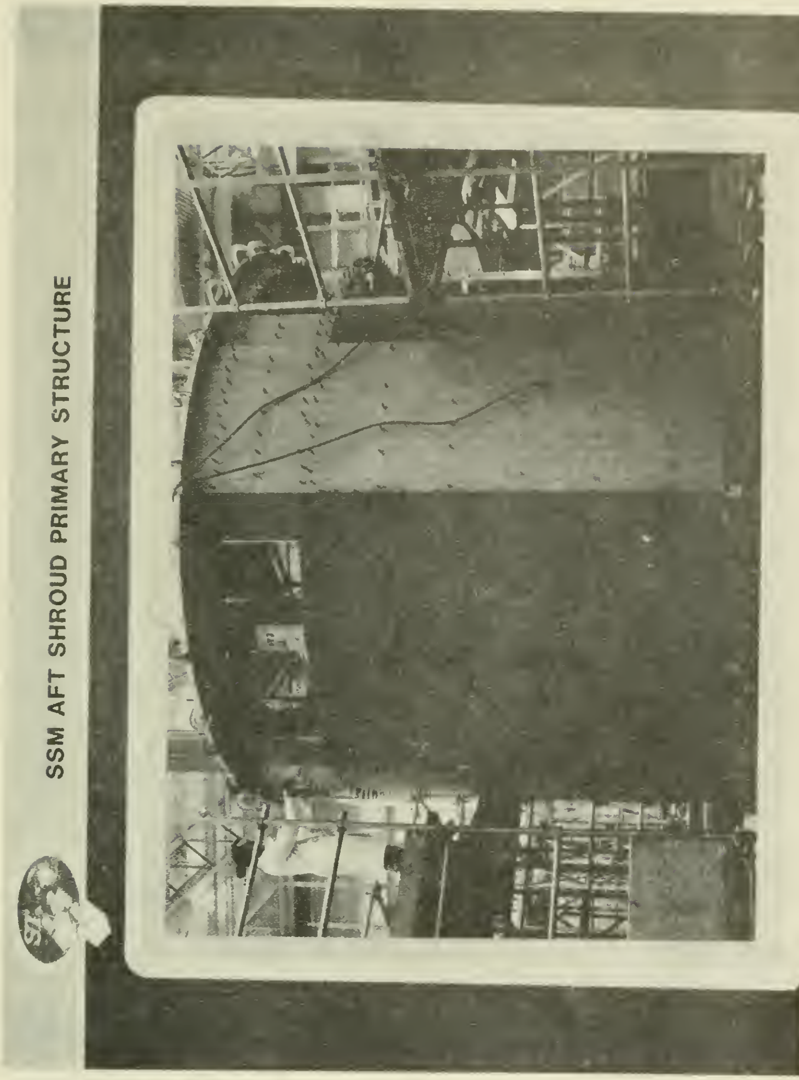

Figure 12

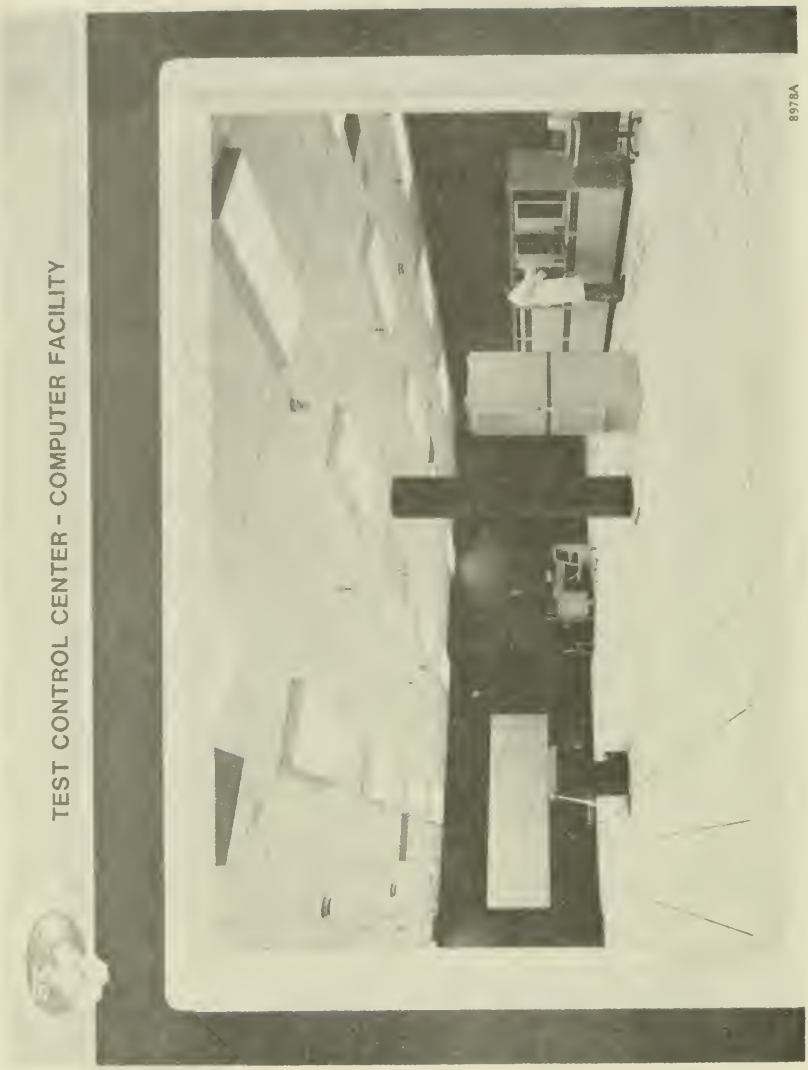

Figure 13

current uses of this facility are: for SSM flight software development and verification, test software development, and engineering data base development. The engineering data base is being delivered on an incremental basis to Goddard for their operations ground system software development.

Shown in Figure 14 is a new building constructed and funded by Lockheed which will serve as an SSM and ST final assembly and test facility at our Sunnyvale, California complex. This facility has been activated and is adjacent to our existing environmental test facilities. This new facility consists not only of one of the world's largest horizontal laminar flow cleanrooms for spacecraft integration, but also the necessary support facilities to house support equipment and people. The cleanroom (50 feet wide, 120 feet long, and 85 feet high) will be capable of meeting Class 10,000 requirements using a horizontal laminar flow system. A 20-ton radio-controlled bridge crane with a 76 foot hook height will service the 6,000 square foot cleanroom. The contiguous support facility contains 47,000 square feet of desk and board and support operations space including 19,000 square feet for the previously mentioned ST Automated Test Software computer system consisting of two Digital Equipment Corporation VAX 11/780 computers and the government supplied command data handling ground test system consisting of a Digital Equipment Corporation 11/70 computer. The new cleanroom opens within the same building housing the spacecraft Vertical Acoustic Test Chamber and the Horizontal Thermal Vacuum Test Chamber.

Figure 15 shows a view of the facility from the second floor observation window when the facility was certified 10,000 class cleanroom and Figure 16 shows the construction of the Vertical Integration stand which will support the ST Assembly and Verification program.

Technical Problems

We encountered problems at the beginning of the fiscal year in the area of structural tooling and sub-assembly fabrication and the replacement of S311 wire in the Equipment Section. The tooling effort was higher than anticipated because of the extremely close tolerances (.005 inch) required on these large

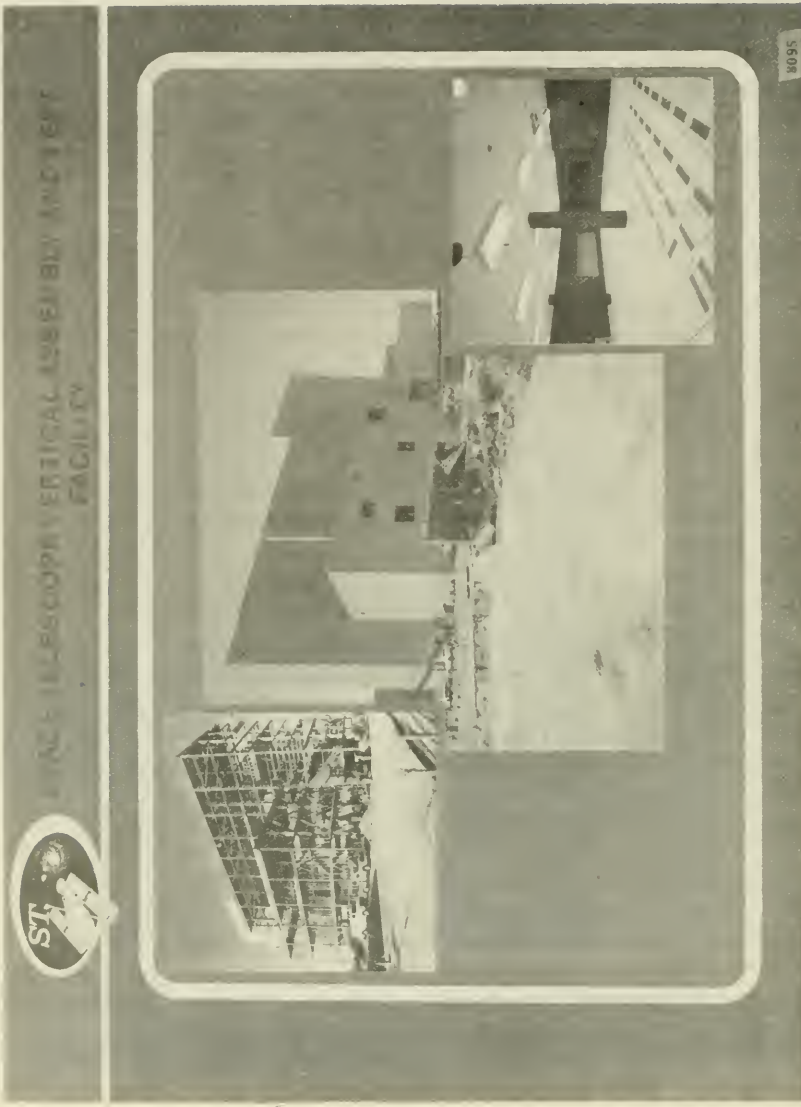

Figure 14

TEST FACILITY CONSTRUCTION
HEPA FILTER WALL FRAMING

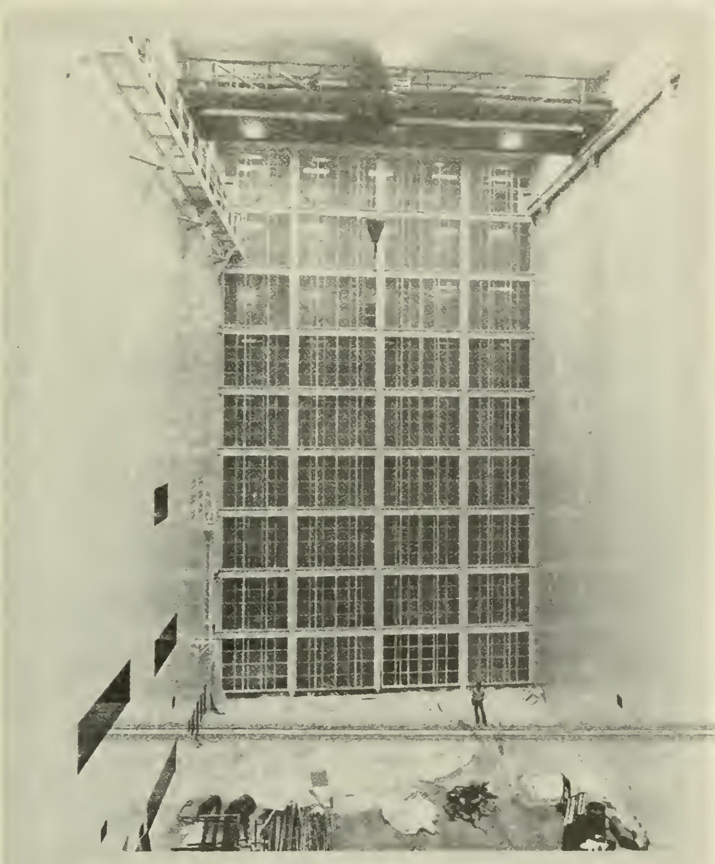

Figure 15

8331A

544

VERTICAL ASSEMBLY AND TEST STAND

Figure 16

8702A

structures. Structural sub-assemblies followed the same problem of extremely close tolerance. These problems are behind us now and the major structures have completed their assemblies ahead of schedule and with zero defects.

The S3111 wire installed in the mockup as Flight Harnesses had to be replaced because of flaking of the blue tracer on the wire which would cause contamination in the cleanroom. This wire had to be removed, form boards made, new harnesses made, and then reinstalled in the mockup. This also has been accomplished and we have established workarounds to factor this late delivery in our current plan.

During this same time period we consciously put into the program a preproduction model of the Data Management Unit. The complexity of this electronic box warrants this action. It serves as the "heart" of the entire ST vehicle since it interfaces with all functional equipment including the digital computers and contains over 60 printed wiring assembly boards containing over 6,000 electronic piece parts connected by a matrix board containing 7,000 wires. The preproduction unit will serve to maintain the key milestones stated previously at the start of hardware/software integration activity and will allow us to check out the automated test stations together with the software that will be used for qualification testing of the flight unit.

Measures have been taken to reduce the flight software memory utilized in the flight computer to assure a 20% reserve available at launch to handle unexpected contingencies. This is being aggressively pursued to avoid changes to the Data Management Unit to handle additional memory.

I feel these problems are behind us now and that we are tracking to the schedule plan.

Challenges and Future Technical and Schedule Risks

Our near term challenge deals with the start of Hardware/Software integration activity. This is the first time we will have physically and functionally integrated flight hardware, test hardware and flight software. These hardware items include the DF-224 Digital Computer, Data Interface Unit, Data Management Unit, Pointing and Control System Simulator and the VAX 1178 ground system computer. Our technical challenge in this regard is the physical compatibility of these hardware, their functional compatibility and the ability of the Flight Software to execute its instructions through all the above hardware elements.

The second area of challenge will be the successful development of a High Gain Antenna pointing system that can support ST communication link requirements without inducing unacceptable vehicle disturbances thereby adversely affecting vehicle pointing stability. This will require a system with the correct balance of antenna stability, pointing accuracy and reactive torques. Testing is underway to define the explicit requirements for optimum performance and to determine existing design capabilities together with changes that could be incorporated in a cost effective manner, if necessary.

The third major challenge is to assure that an accurate Data Base is established for all project elements and procedural inputs are timely to support start of SI/SSM integration and the start of ST Assembly and Verification.

The fourth and final challenge relates to cost and schedule risks for the Program. With the start of SSM Equipment Section testing in mid-1984, our concern is with spares for the Program. Present program spares are limited; however, spare cards for electronics for those electronic boxes that are not completely spared are available and the increased test time included in our new plan further reduces the risk. We have initiated planning to increase the black box spares in critical areas but the majority of these added spares will not be available until the ST assembly and verification time period. The major schedule and cost risk to the program still lies in the ST assembly and verification phase, when all the elements of the program, both hardware and software, come together including the ST Mission Operations Ground System.

Management Realignment

In recognition of the stated need for added emphasis and greater depth in Systems Engineering, we have established a new and separate organization. This organization reports directly to me and will work in direct support of MSFC which has taken a similar step in their structure. It is headed by Tom Harvey who was previously Deputy Program Manager of the SSM and is now Director of Space Telescope Systems Engineering. We have increased the staff from 25 to 70 people and will further increase to over 100 by the end of FY 1983. The objective of this organization is to provide an in-depth penetration of all the modules' technical status and to integrate them into a system which accomplishes the Science objectives. With primary emphasis on the forthcoming ST Test and Verification phase, they will maintain and update technical and test requirements, assure proper verification and compliance with them, audit electronics and hardware interface designs and integrate the critical Pointing Control and Fine Guidance System into an accurate, stable and operational system.

Cost and Funding Plan

Our cumulative costs expended through May are $204.2M against a cost plan of $203.1M. While we are slightly in an overrun position, we are confident that we will meet our funding guideline for the remainder of the Fiscal Year 1983.

We are presently assessing a new funding plan, together with the schedule plan previously shown in Figure 3 for compatibility. We expect to finalize this review with MSFC within the next two months.

To summarize, gentlemen, we are tracking to our new plan within our projected costs and we are performing well. We are looking forward to the next phase of the program in completing fabrication of flight hardware, assembling the SSM and conducting ST environmental testing leading to a fully tested ST to be delivered to Kennedy Space Center for integration into the Shuttle in March 1986.

Lockheed
MISSILES
& SPACE
COMPANY,
INC.

In reply refer to:
LMSC/D928412
Orgn. 60-01, B/104

8 July 1983

Mr. Harold L. Volkmer
Chairman, Subcommittee on Space Science
and Applications
U. S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D. C. 20515

Dear Mr. Volkmer,

With reference to your letter dated 28 June 1983, received by us on 6 July 1983, it was a pleasure to participate in your oversight hearing on the cost, performance and schedule status of the Space Telescope Program.

Enclosed are the answers to the additional questions submitted to us. We hope this response is satisfactory.

Do not hesitate to contact us if we can provide you with any additional information.

LOCKHEED MISSILES & SPACE CO., INC.
SPACE SYSTEMS DIVISION

F. C. E. Oder
Vice President and General Manager

Enclosure

1111 LOCKHEED WAY • SUNNYVALE, CALIFORNIA • 94086

Enclosure to
LMSC/D928412

LOCKHEED MISSILES & SPACE CO., INC.
SPACE SYSTEMS DIVISION
8 JULY 1983

1. Mr. Powell, within the Space Systems Division of LMSC, what percentage of the division's total effort is being devoted to the Space Telescope activities?

   As a function of time, it is 5 to 10% of the Direct Division headcount.

2. Mr. Powell, do the required skills and manpower for the Space Telescope reside within the Space Systems Division?

   Yes.

3. Mr. Wright, do you control all resources needed to accomplish the Space Telescope program?

   Through my SSM Program Manager and Director of ST Systems Engineering, I control the funding resources allocated to LMSC from NASA as well as the assignment of personnel and facilities.

4. Mr. Wright, a number of reviewers suggest that the systems engineering effort has been understaffed in the past.

   a. Do you agree with this assertion?

      The Systems Engineering effort for the Program was austerely but adequately staffed in the Program consistent with the resources authorized by NASA. After our Systems Engineering critical design review, it was further reduced to support hardware development.

   b. Have you previously attempted to gain increased systems engineering staffing?

      Yes.

5. Some of the Lockheed cost growth has been associated with overhead structure changes. Could you elaborate on the reasons for this?

   In the past, the level of inflation had been higher than our negotiated forward pricing rates, thereby requiring yearly adjustments. Government imposed cost accounting STD 418 had significant impact to the Space Telescope when imposed in January 1982. For example, computer related costs went from direct program charge to overhead. Lastly, our overhead rates are based on our direct labor base and are made on an estimated projection of our direct labor force. When other programs have fiscal funding constraints levied or program slowdowns that affect the direct base, our overhead rates are affected.

Enclosure to
LMSC/D928412

6. a. Could you discuss your interface and interactions with Perkin-Elmer?

   LMSC has had good interactions with Perkin-Elmer in the past. We did not have access to the costs, schedules or non-interface interactions due to our associate contractor relationship.

   b. Are there direct interactions or is NASA involved at all meetings and discussions between the associate contractors?

   LMSC and Perkin-Elmer have had bi-monthly meetings without the presence of NASA to discuss management and technical issues and coordinate upcoming meetings. NASA had endorsed these meetings. There also were informal meetings held with the other associate contractors and ESA and their contractors. NASA was not always in attendance for these meetings. NASA Marshall had always encouraged face to face meetings with associates. NASA participated in these meetings when project decisions and contract direction were necessary.

7. What involvement does Lockheed have for the science instrument development? Are there direct interactions with the Principal Investigators?

   LMSC, in developing interface control documents for the Space Telescope, was intimately involved in the initial Scientific Instrument development. We dealt with the contractors providing the experiments, as well as the Principal Investigators. LMSC had no direction authority, and serves in an advisory capacity.

8. What impact has the requirement to provide for maintenance and repair had on cost and schedule?

   The requirements for maintenance and repair were factored into the Space Telescope early in the program. The costs and schedule impacts associated with this activity are minimal at this time and will necessarily increase as we approach launch.

9. a. What steps are being taken to protect the mirror from contamination during the integration, test and checkout activities?

   The assembled ST is in a class 10K clean room at all times during vehicle testing. At all other times (transport out of clean room), the total vehicle is placed in a bag. This bag is only removed during thermal vacuum tests, and while the vehicle is in a certified clean room. A "test" aperture door is installed during these phases to prevent deposition of stray particles from falling on the mirror.

   b. Are you able to keep the mirror covered during most of that time?

   Perkin-Elmer is tasked with investigating a cover for the mirror that can remain on during all test and transport activities.

10. How will the Space Telescope be shipped to Kennedy Space Center?

    The Space Telescope is planned to be shipped from Lockheed by NASA barge to the Port of Alameda, California (San Francisco Bay). It is intended to be transferred to a surface ship for shipment through the Panama Canal to the launch base.

11. Has Lockheed been able to live within the resource estimate for the manufacturing and fabrication effort?

    LMSC required additional resources in manufacturing and fabrication because of additional tooling and detail fabrication costs encountered because of difficulties experienced in extremely tight tolerances on these large structures and detail parts, however this represents less than one percent of contract value.

Mr. VOLKMER. Thank you very much. I do have several questions.

At the present time within the space systems division at Lockheed, what percentage of the division's total effort is being devoted to the space telescope activity; that is, LMSC?

Mr. POWELL. It is in the order of 5 to 10 percent.

Mr. VOLKMER. Has that increased since last year?

Mr. POWELL. It is increasing some as a result of the added task that has been asked to be performed in the systems engineering area, and also I think our manufacturing area had started to build up some as we released these structures into production, but not a great increase.

Mr. VOLKMER. You said because of the added tasks in engineering?

Mr. POWELL. Systems engineering tasks.

Mr. VOLKMER. Requested by whom?

Mr. POWELL. By NASA, Marshall Space Flight Center.

Mr. VOLKMER. Was that as a result of these meetings in January and February?

Mr. POWELL. Yes.

Mr. VOLKMER. Will that increase costs to Lockheed?

Mr. POWELL. It increases the funding at Lockheed, yes.

Mr. VOLKMER. Does the space systems division that you have have all the skilled manpower necessary now?

Mr. POWELL. Yes. I do not think there is much question but we have the required skills to carry out the program.

Mr. VOLKMER. You have all the resources necessary to accomplish the space telescope program?

Mr. POWELL. Yes, sir.

Mr. VOLKMER. Now have you been understaffed in the past?

Mr. POWELL. No.

Mr. VOLKMER. What about systems engineering?

Mr. WRIGHT. I would like to comment on that, if I may.

In terms of understaffing, I feel it has been generally recognized, not only by the separate investigative committees that have been assigned to review the program, ourselves, and particularly Marshall, that the systems engineering was not adequate in terms of the depth of penetration and in terms of the total number of people, especially in recognition of the forthcoming critical phase that we are entering. We need a much greater indepth integration, if you will, in preparing for this vital testing that is coming up. The whole systems engineering aspect has a different flavor from the past. For the most part, the requirements have been pretty well established, and now we need much more detailed visibility and integration for amalgamating and incorporating all of the modules. In that sense, this rephasing, and additional resources are going to improve that greatly.

Mr. VOLKMER. Are you telling me that that would have probably occurred, anyway, going from one phase to the other?

Mr. WRIGHT. It would have been our recommendation, but let's say in this case it has been well recognized.

Mr. POWELL. Maybe I misunderstood your original questions in terms of having people available to meet the requirements of the contracts we were under. We never suffered any shortage due to that. We always had plenty of people to apply to the program, if the program contract called for it.

Mr. VOLKMER. All right. Mr. Wright, could you compare the currently planned milestones that we are looking at now in 1983 with the schedule that we had 13 months ago, when you appeared here in May of 1982?

Mr. WRIGHT. In my last appearance here, as you will remember, when we talked about our downstream schedule planning, it was a success-oriented schedule and that everything would come together by the date specified. We felt, based upon experience with other programs with good success, that it was achievable.

Now, because of the delay of the delivery of the Perkin-Elmer OTA, we can utilize this time by eliminating some of the higher risks in the schedule by adding 4 months to the ST A&V plan. Therefore, instead of being success oriented, I now feel that we have reserve in the schedule to take care of problems that we do not now foresee.

In addition, this extra time has added another 3 months to the SSM testing. We are also taking advantage of that time with early integration of the scientific instruments with the support systems module to further reduce risk. I feel now that we have a schedule that is achievable with some reserve to take care of unknown problems.

Mr. VOLKMER. However, with the extra time in it, do we not also incur additional costs?

Mr. WRIGHT. That is correct.

Mr. VOLKMER. Could you give us an estimate about what the additional cost would be?

Mr. WRIGHT. That is a good question.

Mr. VOLKMER. Submit it for the record in writing.

Mr. WRIGHT. We would be happy to do that.

[The information follows:]

The additional cost relative to the program extension of 15 months at approximately $4M per month is estimated at $60M. This does not include the cost of the risk reducing tasks currently being coordinated with MSFC.

Mr. WRIGHT. The reason I hesitate, Mr. Chairman, is that this whole integrated plan now is in its detailed planning stage and working it out with dollars, schedule, and activities. We are working this out with Marshall. It is going to be a couple months before we get it tied down. We would be very happy to give you an estimate.

Mr. VOLKMER. I would like to give you a hypothetical. Let's say the optical telescope assembly and the scientific instruments had been completed and remained on schedule, as they were as of last year, would Lockheed have been able to make the June 1985 launch date?

Mr. WRIGHT. Yes, we would have. I would add to that, however, that our costs would have increased based upon the old plan because of some of the problems I just described to you, but we would have met the schedule.

Mr. VOLKMER. The problems you are describing in regard to the integration of the data and the computerization and that type of thing?

Mr. WRIGHT. Yes, the data management unit, the digital interface unit that I talked about, some of the manufacturing initial problems we had with our tooling and the replacement of the flight wire, and so on. Those are problems that we have encountered which have laid claim on additional dollars for this fiscal year. That, inevitably, affects the overall cost, as you would expect, even though the dollars involved here are something on the order of $2 to $3 million.

Mr. VOLKMER. Take the flight wire with the stuff that is flaking off. Why did we use that specific wire?

Mr. WRIGHT. Originally, it was recommended by NASA Goddard that we utilize this wire because it had a good characteristic of EMI, electromagnetic interference. We concurred with this recommendation and bought this wire from the vendor. It had successfully been utilized in other NASA spacecraft.

After we received the wire, we noticed this flaking that occurred. Tracing back to the vendor, we discovered that their process had changed. By virtue of this process, this striping on the wire was flaking off, causing the contamination. Therefore, we had to replace it.

Mr. VOLKMER. Did you replace it with wire that was available from other sources?

Mr. WRIGHT. Yes, from the same vendor with the corrected process. I might add this wire is used elsewhere in the ST.

Mr. VOLKMER. Now how much additional cost are we talking about in adding, first, the parts and availability of spares?

Mr. WRIGHT. I do not have that number handy, Mr. Chairman, but the number of spares we are adding is something like—what is it, about 30, Mr. Bulkin? Maybe you can answer that.

Mr. BULKIN. It is about 30 items. Most of our fixed price subcontract deliveries already include a number of spares. The inhouse electronics and the gyros and some of the equipment that Bendix is building for us have to be spared. They represent about 15 items, I believe.

Mr. WRIGHT. We would be happy to give you those costs.

Mr. VOLKMER. I would appreciate that.

[The information follows:]

The cost of additional spares to support the ST Assembly and Verification testing is estimated at $18M.

Mr. VOLKMER. I will just ask you right off. Where do you attribute the increased cost that Lockheed will incur?

Mr. WRIGHT. The downstream cost by a very large percentage will be due to the stretchout of the program. Of course, we are adding additional items which will reduce the downstream risk also, to assure meeting this new schedule.

Mr. VOLKMER. The flight software memory, are we going to have that 20-percent reserve available at launch?

Mr. WRIGHT. That is a very good question. We are in deliberations right now with the systems engineering group at Marshall. We have recommended some solutions which will prevent us from adding additional hardware, thereby not increasing the cost.

However, if some of the reduction in our software that we recommended is unacceptable, for example, to the operations people at

Goddard, we are going to have to make some value judgment here in a tradeoff as to what is the best way to go to minimize cost and schedule and assure the performance we want.

We have a solution that is a no-cost solution, and it remains to be seen whether that will be accepted.

Mr. VOLKMER. No cost solution by changing the type of software?

Mr. WRIGHT. Just reducing some of the software that we feel is desirable but not mandatory.

Mr. VOLKMER. Are some of your costs associated with overhead structure changes?

Mr. WRIGHT. Yes. Due to the inflation situation over the past 5 years being greater than what was assumed for our forward pricing, we experienced higher rates than was originally estimated. In addition to that, we had a CAS 418 which impacted our contract. In some cases, because of the complexity of the program, our direct rates were higher than what we estimated. Therefore, the combination of all three resulted in increased cost due to these three factors.

Mr. VOLKMER. All right. In other words, if everything had been on schedule in the success-oriented program, we would not have had necessarily all these additional costs?

Mr. WRIGHT. Not all of them, but we would have still had some because we have already experienced these increased rates to date.

Mr. VOLKMER. All right. Now in the integration of the hardware—in other words, with the hardware you are going to have and is going to be on board, plus what is going to be at the Science Institute and what is at Goddard altogether, how much time have you allowed to make a determination as to everything is going to be compatible—to make the tests to make sure everything works?

Mr. BULKIN. We have a compatibility test planned that will interface the ST through the TDRS back through Goddard and to the Science Institute. These tests start in the first quarter of 1985 and will continue up through and including the launch base activity. There is about a year and a half of activity that will be divided in 1- or 2-month increments throughout that period.

Mr. VOLKMER. Do you see any unforeseen, at this time, let's put it this way, or possible unforeseen problems, with integration where you may have to have some hardware changes or anything later on?

Mr. WRIGHT. Let me answer it this way: We want to take advantage of this extra time, if you will, for this in-depth penetration that I referred to earlier in the systems engineering sense, to make sure that when we put this equipment together for the first time we do not find fundamental interface compatibilities. That is one problem.

The other thing is that it is extremely important to us in getting all of the software ironed out early because that will kill you. The test that we just started with the 224 computer and all our pointing and data management equipment, with the software will prevent us from having software surprises holding up the real testing of the hardware. In fact, we have even gone so far as suggesting, even though that it is another item of cost, that we try to integrate early, the engineering model of the fine guidance sensor, which is so critical in the total system.

In that sense, we hope we will not have any surprises, but when you put a system together for the first time you are bound to have some problems.

Mr. VOLKMER. Are you working with Goddard on that?

Mr. WRIGHT. Yes, sir.

Mr. VOLKMER. You believe you will be able to work that out?

Mr. WRIGHT. Yes, sir, we do.

Mr. VOLKMER. Other than that, do you have any involvement in the science instrument development?

Mr. WRIGHT. We are definitely involved in the systems engineering sense. Part of our expanded role here—and we are in the process of doing this—is having assigned knowledgeable engineering people who are familiar with our total test program at Sunnyvale to be physically present and part of the final testing of the scientific instruments, so that we understand and appreciate—the scientist's problems and what he expects to gain during this final verification test activity.

Mr. VOLKMER. Has that been your experience in the past?

Mr. WRIGHT. Yes, sir, it has. We find that that is very beneficial.

Mr. VOLKMER. Now what steps are being taken to protect the mirror from contamination during the integration test and checkout activities?

Mr. WRIGHT. Well, there are several activities underway to assure contamination-free environment. I would probably refer this to Perkin-Elmer to a certain extent.

One thing we are planning is to make sure that all the basic structures and equipments that have any contact or are in close proximity to the mirror be baked out to prevent any contamination. During the time it is assembled, we would like to see it completely protected with a cocoon, if you will, or a bag, once this environment is clean, to keep it clean. Of course, this not only takes place in Sunnyvale, but also at the base and integrated into the shuttle.

Mr. VOLKMER. The space telescope will be shipped in what way to Kennedy?

Mr. WRIGHT. The NASA plan right now is by barge through the Panama Canal. I think there are plans underway, however, looking at alternatives to that.

Mr. VOLKMER. I believe you have answered this question. I have made a note on one of your statements that your automated test software computer facility and your new vertical assembly and test facility will be integrated with Goddard and the Space Telescope Science Institute; right?

Mr. WRIGHT. Yes, it will. The Goddard operation facility will be able to command the vehicle through the TDRS link to verify closing and commanding and monitoring the vehicle.

Mr. VOLKMER. On the high gain antenna pointing system, you say testing is underway to define the requirements of optimum performance, et cetera, and design capability. When do you anticipate that you will have overcome these problems?

Mr. WRIGHT. I will refer that to Mr. Bulkin.

Mr. BULKIN. We will complete our initial test in the September timeframe this year.

Mr. VOLKMER. Do you see any difficulties with any proposed funding for 1984, presently proposed?

Mr. WRIGHT. Not at the present time, if NASA will be able to allocate to us the funds we feel we need for this plan that I just described, and our preliminary discussions underway look very encouraging, but we need to get into this in detail down to the fifth level of our work breakdown structure with all facets of the program, to make sure we have a good handle on those costs.

Mr. VOLKMER. I have taken more than my 5 minutes. Now I will recognize the gentleman from California, Mr. Brown, for any questions.

Mr. BROWN. Thank you, Mr. Chairman.

Gentlemen, I do not think I have any penetrating questions, but I am very much interested in this project because of its importance to the scientific community.

Where is the physical location of the activity going on here, in case I should want to visit the operation and see how it looks?

Mr. WRIGHT. There are three basic areas that you should visit, sir. First of all, close by is Perkin-Elmer, of course, where they are in the final phases of much of their hardware, especially looking at this new mirror that has had outstanding performance to date.

At Goddard there are very important test activities this summer and fall called VAP. It is a verification acceptance program where they, for the first time, will be taking the scientific instruments and integrating them with the IBM and Fairchild command and data handling computer, and running a series of tests. That is an important series of tests prior to their delivery to Lockheed.

Then, of course, we would encourage you to visit Lockheed and see our new facility as well as the hardware that we now have.

The major activity within that new facility will not be starting until the middle of next year.

Mr. BROWN. This mirror is not your responsibility. This is Perkin-Elmer. I guess I will ask them about mirrors.

Are you responsible for developing the schemes dealing with pointing and tracking and that sort of thing?

Mr. WRIGHT. This is a direct responsibility between Perkin-Elmer and ourselves. It is a very intimate and detailed interface. Because every single element is tied together both in a physical and functional sense, it is hard to define that interface. Because of that, we and Perkin-Elmer work very closely together in this activity, and in the new systems engineering activity I described we will be taking a much greater, in-depth role in conjunction with Perkin-Elmer with the fine guidance sensor.

Very briefly, the fine guidance sensor is the responsibility of Perkin-Elmer. We have the responsibility for the reaction wheels, the gyros, the star trackers, and the remaining components of the system as well as the overall system architecture.

Mr. BROWN. With regard to the pointing and tracking capabilities of this mirror, none of the work you are doing is classified, is it?

Mr. WRIGHT. No.

Mr. BROWN. Are you able to compare the work that you are doing with some of the studies that are being done on finding and tracking of laser missiles and laser mirrors for purposes of knocking down missiles?

Mr. POWELL. The answer is, yes, we are able to make those comparisons, but the basic problem that one is solving is quite different. The rates at which you wish to track and shoot down an object in near-earth orbit, for example, are much higher than the rates associated with acquiring a star out in space. The stability with which you want to stay on the star is tighter than the stability that you need to burn a hole in another guy's satellite or missile or whatever. The dynamics of the problem are quite different.

Mr. WRIGHT. The stability of the space telescope is unique. It can take its good old time in pointing to something, but once it points, not only is the pointing accuracy severe, but the stability is very severe. This is strictly state of the art. It is something that has never been achieved before and certainly is the key technical driver of the entire design of the vehicle.

Mr. BROWN. Mr. Powell says that is a slightly different problem than being able to rapidly acquire and stick to it. Are they of comparable difficulty, or is it possible to make a statement?

Mr. POWELL. I would just roughly guess that they are comparable.

Mr. BROWN. What is the nature of the gyro system that you have?

Mr. WRIGHT. The gyro that we are using has its genesis in other NASA programs. Also, in our other programs we use this generic group of gyros. The uniqueness of this gyro, however, is that we have developed and incorporated a shroud in the gyro to cut down the noise, both electronic and mechanical, which had a feed through into the pointing control system. That is new for this country. It is probably the best gyro that has ever been built in that sense.

Mr. BROWN. Is it a mechanical gyro or——

Mr. WRIGHT. It is a mechanical gyro.

Mr. BROWN. There are other kinds of gyros, aren't there—laser gyros? Would they be better or worse for a situation like this?

Mr. WRIGHT. A laser gyro would still have some of the basic noise problems perhaps. However, incorporating something like that at this stage would be out of the question.

Mr. BROWN. What about the next one?

Mr. WRIGHT. There's a possibility.

Mr. BROWN. Thank you.

Mr. VOLKMER. Thank you.

The gentleman from Florida?

Mr. MACKAY. No questions.

Mr. VOLKMER. The gentleman from Virginia, Mr. Bateman?

Mr. BATEMAN. No, Mr. Chairman. Given the vagaries of my schedule, I think I am going to learn more by listening than by asking, so I will pass.

Mr. VOLKMER. I have one final question.

I could probably go through the figures here and take time and figure out what is and what isn't—on figure 6 you gave all the flight hardware. Is all of that fully tested out and ready to be assembled?

Mr. WRIGHT. Yes. As I said before, approximately one-third of the total complement of our flight hardware has been acceptance tested, qualified, and in storage awaiting assembly into the SSM. The remaining two-thirds of all of our equipment is in the final fabrication and test phase. We still have two critical qualifications yet in terms of the data management unit and the digital interface unit.

Mr. VOLKMER. I have no further questions. I want to thank you very much for being here.

Wait a minute. I am going to go over just one more thing.

When you testified here—and I think we have covered it but I just want to emphasize it from my own viewpoint—when you testified here last year and talked about the schedule at that time, you were positive that you would be able to stay with that schedule and complete it. I have asked you if the other things have been delivered on time. The new schedule that you are now following was not a result of anything that occurred at Lockheed?

Mr. POWELL. That is correct.

Mr. VOLKMER. Thank you very much.

Our next witnesses are Gaynor N. Kelley, Perkin-Elmer Corp., along with John D. Rehnberg.

Gentlemen, your statements will be made a part of the record, and you may either review them or summarize them, however you so desire.

STATEMENT OF GAYNOR N. KELLEY, EXECUTIVE VICE PRESIDENT, PERKIN-ELMER CORP., ACCOMPANIED BY JOHN D. REHNBERG, VICE PRESIDENT AND GENERAL MANAGER, SPACE SCIENCES DIVISION, PERKIN-ELMER CORP., KENT MESERVE, GENERAL MANAGER, SYSTEMS OPERATION DIVISION, AND DON V. FORDYCE, DIRECTOR, SPACE TELESCOPE, PERKIN-ELMER CORP. SPACE SCIENCE DIVISION

Mr. KELLEY. Thank you, Mr. Chairman and members of the committee.

I would like to summarize, if I could, the statement I have submitted for the record.

It is, indeed, also my pleasure to be with you this afternoon in discussion of the activities of our space telescope.

First, let me say the Perkin-Elmer Corp. is committed to the completion of designing, fabricating, and testing of the optical telescope assembly of the space telescope and doing this job well. Perkin-Elmer is a 50-year-old company whose heritage has been dedicated to high technology. Over the years we have had the pleasure of serving the Government's science community in many varied and successful programs.

In both my acting capacity as optical group executive as well as my executive vice presidency, I have spent a significant portion of my time on space telescope over the past 5 months. I am planning to continue to do so until this job is complete.

We have made significant management changes to support space telescope which will be described later. At this time all elements of the corporation's resources required to accomplish this task are available and report to me. In all candor, I must say that we have contributed to the problems which were brought to your attention at these hearings. Principally, we misjudged the technical complexity of a number of tasks and, therefore, the time and effort required to accomplish these tasks. This in turn resulted in inaccurate and late projections of the resources required.

While I believe these problems are largely behind us, the remaining effort is still very demanding.

Our product to date has been technically superb, and we are committed to continuing to provide this excellence through the remainder of the ST program.

With me today are Jack Rehnberg, vice president and general manager of our space science division; Kent Meserve, general manager of our systems operations division; and Don Fordyce, the director for space telescope for Perkin-Elmer.

I would like to introduce Jack Rehnberg now, who will report on our current status. We will be happy to answer any questions following Mr. Rehnberg's comments.

Mr. Volkmer. You may proceed, Mr. Rehnberg.

Mr. Rehnberg. Mr. Chairman and members of the subcommittee, concluding our testimony during this subcommittee's space telescope program oversight hearing in May 1982, we acknowledged the optical telescope assembly as a very challenging technical endeavor and identified several areas of concern yet to be faced. We have achieved considerable progress on these concerns and on the program in general. The publicity that the space telescope program has received in recent months has raised the notion that the program is in grave technical difficulty, and as a result less science may be accomplished. Be assured that is not the case. In fact, the science results may even be better than specified.

Perkin-Elmer has its reputation and pride at stake in a business area that has been one of our cornerstones since the company was formed. We will do everything in our means to provide the science community with a telescope equal to or better than what they have asked for. For the public record, therefore, this testimony will review the technical requirements and challenges from the program outset in 1977, our accomplishments, and the status of recent technical concerns. I will also discuss factors affecting program growth, the management improvements effected since May 1982, and the schedule to which we are now committed with our partners: NASA, Lockheed, and the ST science community.

The original performance specifications of the space telescope are shown in the figure on my right. These demanding specifications have not been changed to this date. Without discussing them all in detail, I would like to mention the two principal performance requirements which drive all elements of the optical telescope assembly design. These are the requirements relating to image quality and image stability. Image quality requirements are stated as lambda over 20 system wavefront error or a variance of one-twentieth of the wavelength of light for periods of up to 10 hours. The image stability requirements are stated as a 0.007 arc second line-of-sight error on a magnitude 13 guide star.

The major technical challenges associated with the optical telescope assembly were identified at the beginning of the contract in 1977 and these challenges are summarized on the chart on your left. They relate, of course, to those two principal performance requirements identified in the previous chart. They involve the stability of the primary mirror to secondary mirror spacing, the stability of the focal plane structure supporting the science instruments, the quality of the primary and secondary mirrors which control the system wavefront error, and the reflectivity of each of the mirrors in order to provide adequate performance in the ultraviolet region of the spectrum.

Also of critical performance is our ability to aline the system on orbit using the wavefront sensors in order to begin telescope operations. The noise equivalent angle error in the fine guidance sensor when operating on an even fainter than magnitude 13 guide star is also of critical importance.

The following statements that I will make relate to these performances. In general, each of these original challenges have been met, and in many cases we have measured performance data which show the telescope will meet all of its original performance requirements.

The chart on your left shows a generic buildup of the telescope, the process we are currently undertaking. In the upper lefthand corner we see the primary mirror being assembled into the main ring. Next the baffles will be mounted into the primary mirror and main ring. We then marry in the flight focal plane deck which holds the science instruments, and lastly the secondary mirror assembly must be alined critically to the primary mirror. Then we have the final assembly in the lower righthand corner.

I will now sequentially take you through some of the hardware subassemblies that relate 1-for-1 with the particular diagram shown in this cartoon.

We have already accomplished last year the integration of the graphite epoxy truss structure to the main ring shown here.

The flight focal plane structure has been completed and is being prepared for shipment to Marshall Space Flight Center where it will undergo vacuum outgassing.

Entirely covering the space telescope and around the primary mirror are perhaps 800 heaters and temperature controllers of the type you see here. These are essential to control the critical surfaces to one-tenth of a degree. This type of temperature control is necessary in order to achieve the kind of performance that the science community expects from the space telescope.

Next chart, please. Typical heater—that which is being applied to the main ring as well as the other associated hardware on the program.

Here again we see the flight focal plane structure as it is being harnessed with its heaters and cabling.

The primary mirror which has been integrated into the main ring—and I will show you charts on that very shortly—is shown here during a polishing process 2 years ago.

We developed, under the space telescope program, a computer-controlled process unequaled in the world for finishing the mirror, not only to the desired figure quality but to the necessary smoothness, which was absolutely necessary for the ultraviolet performance.

Next chart. This is a photograph of the secondary mirror. Although it does not receive the publicity that the primary optic does, it is an equal partner in providing the precise fidelity of imagery that is necessary for the space telescope. The challenge of fabricating that was no minor task in itself.

Next chart. Also in one of our Connecticut operations, a very unique facility had to be developed and brought on line. We did show you this at last year's hearings, the coating facility for coating the primary and secondary optic.

Next chart. This is the mirror being removed from the coating chamber in preparation for further integration.

Next chart. Here we see the mirror being inspected following the final coating operation.

Next chart. I would like to dwell on this chart for a moment. We see here the requirements as they were laid out for the space telescope reflectivity for the primary and the secondary in the visible as well as the ultraviolet. The performance requirements have been met or exceeded at all portions of the spectrum.

On the primary mirror, you can see we have achieved 78 percent reflectivity; on the secondary, 73 percent reflectivity. We have not evidenced any change in reflectivity on witness samples that were coated at the same time that the primary mirror had been coated a year and a half ago.

Next chart. I would like to walk you quickly through some of the operations that we have been undertaking during this past year in preparation for integrating the primary mirror into the main ring, which was accomplished successfully in March of this year.

You see here some of our technicians assembling hardware to the back of the mirror and to the sides of the mirror. As you can see, during all of these operations, which took approximately 18 months, the mirror has been protected and covered when it was in these kinds of clean room conditions.

Next chart. The mirror here is shown being lowered into the main ring. You can see the critical attachment fixtures on the back of the mirror which must tie it into the main ring. This task took 5 months and had to be accomplished in a very precise manner, such that the zero gravity environment could be simulated. We did not disturb any of the figure quality that was implicit in the mirror prior to attachment to the main ring.

Next chart. Here we see the primary mirror integrated into the main ring. This, in my estimation, is probably the most significant event for the space telescope program. I do not think anything of this magnitude with this precision and size has ever been accomplished before, and I am very proud of our people, having accomplished this for the first time; albeit they were 5 months late in the accomplishment.

Next chart. Again, I mentioned that the secondary mirror is an equal partner to the primary. Here we show the secondary assembly with the secondary in it. It has a very critical 5-degree freedom actuation mechanism and must also be aligned to submicron precision. It is being prepared here for vibration testing, which is scheduled for the months ahead.

Next chart, please. You see here an optical high fidelity bread board of the optical control sensor which is used for sensing the star light coming in through the telescope, and information from that interferometer is then transmitted to the ground station. We derive polynomials from that, and from that information determine the alinement requirements for the primary and secondary mirrors, and can control the position by actuation mechanisms in order to assure telescope alignment.

Next chart. The fine guidance sensor, which many of you have heard so much about, is a rather complex subsystem, as Mr. Wright also alluded to. It is the heart of providing information on the guide stars such that the telescope can obtain the 24-hour pointing stability requirements.

There are several electronic subsystems associated with it as well as an interferometer and some other critical optical subsystems.

Next chart. We are in the process of assembling the first engineering unit of this fine guidance sensor. We see here a graphite epoxy bench structure, which is the heart of the fine guidance sensor assembly and holds the critical dimensions necessary for this unit.

Next chart. This is a photograph of the star selector servo assembly provided by BEI. Again, this system has proven its worthiness, and it is ready for integration into the engineering unit.

Next chart. Typical of the electronic units, this is an engineering model of the fine guidance electronics provided by Harris, and we are waiting arrival of the first flight units of that subsystem this summer.

Next chart. I would like to briefly dwell on the system performance improvements that have been attendant to the program since its outset. With the added image quality predicted for the primary and secondary mirror, with the increased reflectivity that we expect to receive from the primary and secondary mirrors, we can assure the science community that the telescope that will be provided by Perkin-Elmer to NASA at this point in time will meet or exceed even those goals established when the space telescope was planned to be a 3-meter facility.

Next chart, please. I would like to now discuss some of the concerns—that were raised this past year which have led to some delays in the program and address briefly what has transpired and where we feel we are at this point in time.

Those were specifically the attachment mechanisms or the latches for the science instruments, the fine guidance interferometer, and, lastly, the contamination.

The chart on your left is a photograph of a typical latch mechanism. There are 27 of them. They must retain the science instruments to the flight focal plane deck to a very precise tolerance dimensionally and angularwise. As you can see here, it is approximately the size of a football, to put it into perspective.

That large coil spring there is the kind of mechanism that must be preloaded. Again, it is designed to provide precision tolerance. It must be onorbit replaceable, such that an astronaut can remove an instrument and then reinsert another instrument without losing precision and alignment.

I am pleased to say that we have successfully completed revalidation testing of the latches associated with this design during March and April of this year, and at the present time we are proceeding ahead with the final manufacturing retrofitting of the latches associated with this program.

Next chart. The problems that occurred most recently had to do with the hardness of that ball that you see in the chart on your left. We had to change the material to a tungsten carbide material. That changeover was successful and, as I stated, was qualified most recently.

Next chart. The next chart shows, again, the mating part of the socket to the ball shown in the previous chart.

Next chart. I would like to now briefly discuss a concern that was raised last year concerning the flight focal plane structure. This is the first program which has extensively used graphite epoxy in strength-critical structural applications. While this material has been used in the past for optical benches and while Perkin-Elmer has used it many times for such applications, such use requires stability and stiffness but rarely strength. In the case of the focal plane structure, we are dealing with an optical bench capable of supporting five scientific instruments and three fine guidance sensors weighing a total of over 4,800 pounds. Thus, in the Space Telescope the focal plane structure has to support all that hardware through shuttle launch and landing. As a result, strength becomes a critical parameter in the design of the focal plane structure.

The region of the focal plane structure shown as the flexure is a blade of graphite epoxy which interfaces the focal plane structure to the aft face of the main ring. This blade takes the entire weight of the structure and the fine guidance sensors and the scientific instruments. The lowest section of this element, called the flexure foot, was strength tested and failed when subjected to the shuttle loads. After a very extensive design analysis activity, a redesigned flexure foot was built, tested, and was proven successful. That repair has now been implemented on the flight focal plane structure and is shown in the figure on your left. Each of the flexure feet are now sandwiched into a titanium fitting known as a titanium boot. The boot is bolted through the flexure and, in addition, is bolted to the main ring, thus providing the reinforcement necessary in the critical region of the flexure foot.

Tests have shown that the flexure feet and the flexures are adequately strong. Again, that problem is behind us, and the necessary repair that we had discussed with you last year has been accomplished.

The last item, dealing with contamination—a remaining concern relates with regard to contamination. As you will recall, this was brought to your atte ıtion by Dr. Frank Martin of NASA last year and is one that we need to be concerned about.

There are two kinds of contamination, one in the form of dust particles and the other in the form of hydrocarbon contamination on the primary mirror. It should be noted that the primary mirror has been kept in the cleanroom ever since it was coated in December of 1981. Further, that cleanroom is well maintained and the air quality is monitored continuously. Nonetheless, no cleanroom is perfectly clean, and some dust particles are always present. Therefore, over a period of time an exposed surface will gather dust even in the cleanroom, and the primary mirror proved to be no exception. This has proved to be the case even though the mirror has been covered while it was not actually being worked on.

In the intervening year and a half since the mirror was coated, dust particles have settled on the surface. The question now is what to do about it. Is it acceptable to leave it as is or should some attempt be made to clean the mirror?

It was recognized that any attempt to clean the mirror has an attendant risk of damage to the mirror coating. Significant analyses have been recently conducted. Samples of the dust have been gathered, and photographs of the dust particles have been made in order to count their number and to measure their size.

Preliminary conclusions are that the ultraviolet region of the spectrum of the primary mirror is marginally acceptable as is. In the visible region of the spectrum, the primary mirror will be adequate as it is at this moment.

The concern remains, however, that the primary mirror will accumulate more dust before the space telescope is launched. Thus, some performance margin is needed to accommodate the additional dust buildup which is inevitable between now and the launch date. Perkin-Elmer is, therefore, planning a cleaning activity which will be conducted as late as possible, probably in the summer of 1984, and will result in the removal of a significant portion, but not all, of the dust particles on the mirror.

The cleaning mechanism to be used is currently envisioned as a benign operation in which the dust is blown with clean, dry air or filtered nitrogen and simultaneously vacuumed away with a vacuum hose. Tests to date have shown this approach to result in a successful removal of small dust particles.

A proper cleaning fixture needs to be designed and fabricated between now and next summer. The cleaning operation would be conducted with the mirror placed upside down so that no hardware has to be supported above the primary mirror with the risk attendant in that operation.

Measurements have shown that dust at this moment obscures no more than two-tenths of 1 percent of the primary mirror surface.

In addition, reflectivity measurements of witness mirrors placed and maintained near the primary mirror at all times have shown no evidence of molecular contamination.

Due to the significance of the ultraviolet spectrum of this type of contamination, however, we are considering the advisability of direct measurement on the primary mirror surface. Such contamination would be significantly more difficult to remove and more damaging in its effect. We do not expect any hydrocarbon contamination, but we will continue to monitor for it and test as appropriate to insure the ultraviolet throughput is guaranteed at launch.

Based on the above data, we are confident that by the time the OTA is shipped from Perkin-Elmer it will be a clean telescope with a high performance set of optics. These optics will essentially not be degraded by the assembly process, by handling in the plant, or by any contamination that may have resulted in the intervening years.

Mr. VOLKMER. Mr. Rehnberg, at this time I am going to have to have a recess. We have a vote on the floor. We will return in about 10 or 15 minutes.

Mr. REHNBERG. Yes, Mr. Chairman.

[Recess.]

Mr. VOLKMER. Mr. Rehnberg, you may proceed with completion of the statement. I believe we were on the fine guidance system interferometer.

Mr. REHNBERG. Thank you, Mr. Chairman.

During phase B studies in 1973 through 1975, an interferometric form of fine guidance sensor was selected as being the best way of achieving sensitivity for pointing errors as small as 1/1000 of an arc second. This form of sensor was built and demonstrated in the laboratory by Perkin-Elmer in 1976. Recently, some of the flight interferometers tested exhibited anomalous transfer characteristics. Since we had previously shown the interferometer scheme to work, we were sure that the anomaly was peculiar to that particular test and not generic to all interferometric fine guidance sensors. After thorough analysis and further testing, the problem has been isolated to the manufacture and test methods employed to make the interferometer prisms. These methods have been revised, and those prisms in the laboratory which were faulty are being reworked.

While we are confident that there are no known fundamental design problems in the fine guidance sensor, additional effort will be required in resolving Koesters prism fabrication and assembly difficulties. The fine guidance system assembly, alinement, and testing will present a formidable effort requiring the application of our highest skilled optical work force.

I would like to review briefly some of the factors which affected program growth. In previous remarks to the committee, we expressed optimism that we could deliver the OTA in December 1983, within the cost projected at that time. This confidence was based on the quantity of critical hardware already on hand and the progress we had made to that point in meeting technical challenges on the program, including especially the successful completion of polishing and coating the primary mirror.

However, as we also pointed out during last year's hearing, almost all hardware on the OTA is state of the art, and some very difficult tasks still lay ahead.

Inflation naturally has been an impact on the program since the inception in 1977 and, as we all know, in the late 1970's and early 1980's the inflation figures amounted to double figures.

A success-oriented approach, as was mentioned earlier in these hearings, certainly brought with it attendant risks.

Naturally, on a program of this type, which is at the leading edge of technology, technical problems will result and always result.

Program changes, again, from these technical problems must be handled and dealt with swiftly.

Interface redefinitions, particularly at a time when the shuttle was going through its development flight test activities, brought on other changes, particularly in the area of loads to which we had to design the telescope to.

Next chart. I have listed here some of the key items which have affected the technical cost growth during this time period. I will highlight a few for you. We mentioned them earlier: the flight focal plane structure, which I discussed in detail; fabrication of the large optical elements themselves; the shuttle loads, which brought with it attendant reanalysis and revalidation of a number of the major structures; fine guidance sensor and pointing-control system changes that were necessary in order to work very effectively with our associate contractor, LMSC; the problem associated with the flexure modifications on the flight focal plane structure; and, last, the instrument retention mechanisms or latches, which in themselves were quite complicated but also had a failure that we had to repair.

Next chart. I would like to briefly review some of the management actions that we have taken since May of last year, to address some of the shortages in the program.

In August of 1982 we were successful in gaining the services of Mr. Don Fordyce, who is the Program Director, at my left. Don has many years of experience in aerospace programs of this type, and since his arrival at Perkin-Elmer has been a tremendous asset to the program.

We have restructured some of the technical management of the program to provide a more focused direction to anticipate problems in advance. Robert Jones, who had been Deputy Director of the program, was brought on my staff as the chief engineer for the space telescope program, reporting directly to me. Bob does not have administrative responsibilities, anymore. Mr. Jones can now focus his attention totally on looking forward and assuring ourselves that we are on the righ track technically.

In the structure below the Program Director, we have revised the program organization such that we now have two Deputy Program Directors. We have one for the optical telescope assembly, to provide a focus of resources for the telescope assembly by itself, and another Deputy Director for the fine guidance system. In this way we provide equal visibility and equal control of resources to these critical components of the optical telescope assembly.

We have also fully staffed and colocated all of the subsystem teams associated with the optical telescope assembly. These are all the personnel associated with the respective subsystems at a common location. We have accomplished a staffing buildup since January of this year. We reviewed that with Mr. Beggs in February. I am glad to say that at the present time we are at the full complement of staffing that we outlined to him at that time.

Last, we have provided additional clean space such that we can parallel assembly all the necessary flight hardware needed for the program.

Perkin-Elmer developed forecasts in December 1982 and January 1983 which, although high in technical risk and schedule risk, could have resulted in optical telescope assembly delivery in June 1984. Subsequent adoption of recommendations made by Perkin-Elmer to reduce fine guidance sensor development risk and the addition of NASA-directed thermal vacuum bakeouts to reduce risk of molecular contamination resulted in the current optical telescope assembly shipped to Lockheed, date of November 1, 1984.

The current OTA schedule at the summary level is shown on your left.

In summary, throughout the OTA development activities, adherence to the original technical specifications has been maintained. Not one of the original requirements has been reduced.

The scientific community was delighted to learn of the excellence of the primary mirror. We anticipate continuing such achievement to support the very important science mission of space telescope.

The schedule slippage encountered has been the result of two basic reasons: technical problems—nearly every optical telescope assembly subsystem presses the state of the art—and annual fiscal constraints which restrain the ability to overcome technical difficulties. Attendant to these difficulties are slippages and, as has been seen, an increase in program cost.

There remains an acute awareness of the difficulties and importance of the space telescope program. We are working to a detailed plan which should require little, if any, future modification. Almost all of the flight hardware is in-house and final assembly and tests are underway, as I have shown you in these charts.

We have not always been in the position to anticipate the unexpected, and our response on occasion may have been slower than would have been preferred, but Perkin-Elmer now is in the position to solve any problems which might arise. The changes in organization, staffing, and program controls have greatly benefited the space telescope program.

Challenges still remain ahead, but we are dedicated to deliver the best estronomical telescope that meets all of the original program requirements.

Thank you, Mr. Chairman.

[The prepared statements, plus answers to questions asked of Mr. Kelley and Mr. Rehnberg, follow:]

Statement of

Mr. Gaynor N. Kelley
Executive Vice President

THE PERKIN-ELMER CORPORATION

before the

Subcommittee on Space Science and Applications
Committee on Science and Technology
House of Representatives

June 16, 1983

Statement of

Mr. Gaynor N. Kelley
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THE PERKIN-ELMER CORPORATION

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Mr. Chairman and Members of the Subcommitte:

I am pleased to have this opportunity to provide you with some brief comments on Perkin-Elmer's activities in support of the NASA Space Telescope program. I would like to tell you that I am the Executive Vice President of the Perkin-Elmer Corporation; my position in the Corporation is shown in Figure I. As you can see, I wear "two hats", since I am also the acting Senior Vice President of the Optical Group. I have acted in this latter capacity since February first of this year by my own choice. My reasons were basically twofold: First, to become more familiar with Perkin-Elmer's government business and second, to become more knowledgeable with regard to the problems we were having on the NASA Space Telescope program.

In support of this familiarization effort, I have met with key members of the NASA, Lockheed and Perkin-Elmer Space Telescope program offices and management staffs. Since I have added my second hat, I have personally reviewed the program status at least twice a week. Based on this educational process we have made a number of significant management changes in Perkin-Elmer's Space Telescope Program office. These will be described in detail by Mr. John Rehnberg, Vice President and General Manager of the Space Science Division of Optical Group. This is the performing division for our Space Telescope contract.

Wearing my other hat, that of Executive Vice President, I have reporting to me all elements of the Corporation required to do this job. I have used this position to promote the transfer of skills into the ST program office and its engineering and manufacturing support functions. When I return to only one job, I propose to continue to interact with the events on Space Telescope until the job is successfully completed. I can unequivocably state that I have the support of my management in following this course.

Let me also say at this time, that the Perkin-Elmer Corporation is committed to completing the job we started on Space Telescope in a manner that will reflect credit on us all: That is doing the job and doing it well. In the conduct of our effort to date, we have accomplished many difficult tasks, including, for example, polishing, coating and mounting of the primary mirror. This mirror is recognized to be the finest of its kind in the world. However, in achieving this and other program tasks, we have contributed to and been the cause of many of the problems brought to your attention during these hearings. I believe that the principal reason for this has been our misjudgement of the technical complexity of several of the tasks required. As a result, our forecasts of the resources required for these efforts were inaccurate and often late.

Today, I am firmly convinced that these problems are largely behind us. A majority of the state-of-the-art flight hardware is at the Perkin-Elmer plant awaiting final assembly, integration, and test. Based on tests conducted to date this hardware meets or exceeds all original program specifications. Indeed, we at Perkin-Elmer are quite proud of its status.

Nevertheless, the job remaining is still very demanding. The assembly and integration activities which I noted earlier, required a level of precision in the ground support equipment that has rarely been achieved for hardware of this type. Based on our previous program accomplishments, however, we are confident that we will meet these demands and continue to provide technical excellence throughout the program to its completion. We recognize, in addition, that these efforts must be accomplished on schedule and within projected costs. All of us at Perkin-Elmer are committed to achieving all three of these factors.

Now I'd like to introduce Mr. John D. Rehnberg, Vice President and General Manager of the Space Science Division, who will present our answers to your questions.

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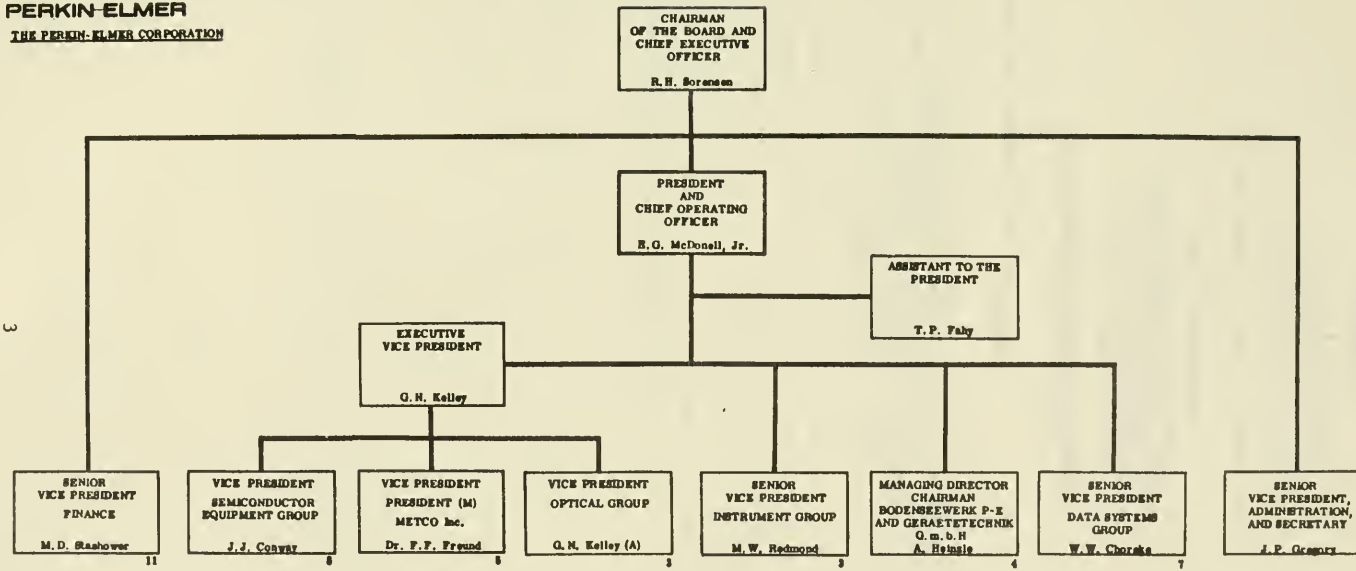

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Statement of

Mr. John D. Rehnberg
Vice President, General Manager
Space Science Division

THE PERKIN-ELMER CORPORATION

before the

Subcommittee on Space Science and Applications
Committee on Science and Technology
House of Representatives

June 16, 1983

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Mr. Chairman and Members of the Subcommittee:

Concluding our testimony during this subcommittee's Space Telescope Program Oversight Hearing in May 1982, we acknowledged the Optical Telescope Assembly (OTA) as a very challenging technical endeavor and identified several areas of concern yet to be faced. We have achieved considerable progress on these concerns and on the program in general. The publicity that the Space Telescope (ST) program has received in recent months has raised the notion that the program is in grave technical difficulty, and as a result less science may be accomplished. Be assured that is not the case; in fact, the science results may be better than specified. Perkin-Elmer has its reputation and pride at stake in a business area that has been one of our cornerstones since the company was formed. We will do everything in our means to provide the science community with a telescope equal to or better than what they have asked for. For the public record, therefore, this testimony will review the technical requirements and challenges from the program outset in 1977, our accomplishments, and the status of recent technical concerns. I will also discuss factors affecting program growth, the management improvements effected since May 1982, and the schedule to which we are now committed with our partners: NASA, Lockheed and the ST Science community.

TECHNICAL REQUIREMENTS AND CHALLENGES

The original (1977) performance specifications of the Space Telescope are shown in Figure 1. These demanding specifications have not been changed to this date.

Without discussing them all in detail, I would like to mention the two principal performance requirements which drive all elements of the Optical Telescope Assembly design. These are the requirements relating to image quality and image stability. Image quality requirements are stated as a $\lambda/20$ system wavefront error or a variance of 1/20 of a wavelength of light ($\lambda/20$) for periods up to ten hours. The image stability requirements are stated as a 0.007 arc second line-of-sight error on a magnitude 13 guide star.

The major technical challenges associated with the Optical Telescope Assembly were identified at the beginning of the contract in 1977 and these challenges are summarized in Figure 2. They relate, of course, to those two principal performance requirements identified above. They involve the stability of the primary mirror to secondary mirror spacing, the stability of the focal plane structure supporting the science instruments, the quality of the primary and secondary mirrors which control the system wavefront error, and the reflectivity of each of the mirrors in order to provide adequate performance in the ultraviolet region of the spectrum. Also of critical importance is our ability to align the system on orbit using the wavefront sensors in order to begin telescope operations. The noise equivalent angle error in the fine guidance sensor when operating on an even fainter than magnitude 13 guide star is also of critical importance. The following paragraphs review each of those issues and describe the progress that has been made since project inception in 1977. In general, each of these original challenges have been met and, in many cases, we have measured performance data which show the telescope will meet all of its original performance requirements.

TECHNICAL ACCOMPLISHMENTS

Metering Truss

Looking first at the question of stability of the secondary relative to the primary mirror, the dominant term in the focus of the image formed by the telescope on orbit, is controlled almost exclusively by the expansivity with temperature changes of the structure we call the metering truss. This truss-like structure cantilevers the secondary mirror some 200 inches or so in front of the primary mirror. The accuracy required of that structure is such that it remain stable to within 199 millionths of an inch for a period in excess of 24 hours in the presence of temperature changes in excess of 30 degrees Fahrenheit. As a consequence, the structure is required to have a very low coefficient of thermal expansion. The graphite epoxy metering truss (shown in Figure 3) has been built and has been tested in a thermal vacuum chamber to simulate the flight thermal environment. It has been demonstrated to meet or exceed all performance requirements. For example, the actual spacing change of the metering truss was measured as 71 millionths of an inch under the flight thermal environment. The test results are summarized in Figure 4.

Focal Plane Structure (FPS)

The focal plane structure is another major structure of the Optical Telescope Assembly whose principal design requirement is one of stability. Because it relates the position of the focal plane of the science instruments and the fine guidance sensors, it is necessary that it not significantly expand or contract during the 24-hour exposure period and in the presence of the changing thermal environment of low earth orbit. In addition, the changing temperatures of scientific instruments, as they are switched on and off to accomplish the observation program, should not impact the thermal stability of the focal plane structure. For these reasons the focal plane structure is also constructed of graphite epoxy to take advantage of its low coefficient of thermal expansion and its light weight and high stiffness characteristics. It should also be noted that the FPS is a strength critical structure, and thus is of primary importance.

The focal plane structure, shown in Figure 5, now has been completed, has been tested, and shown to be stable in the presence of specified thermal changes.

Temperature Control

An important part of the structural stability question is that of temperature control. The metering truss is wrapped in multi-layered insulation and is temperature controlled by entirely passive means. However, the focal plane structure which is affected by temperature changes from the science instruments in intimate contact with it, must be temperature controlled by active means to maintain the required precision. To accomplish this, a large number of heaters are cemented to the focal plane structure. These heaters are controlled by a large number of temperature controllers. Ordinarily a temperature controller would be located remote from the heater, would respond to a sensor in proximity to the heater, and modulate the power provided to the heater to control the temperature. Configured in this manner, the temperature controller would consume power and thus not be 100% efficient. That is, some power would be used in the controlling circuitry in the attempt to control the main power in the heater. To conserve power and weight, a hybrid temperature controller was developed for the OTA by Perkin-Elmer. This miniature electronic circuit, shown in Figure 6, is cemented to the structure with its heater. Since it is in close proximity to the heaters, it not only reduces significantly the weight of cable required for the over 800 temperature controllers on the OTA, but also the power dissipated by the controller contributes to the power provided by the heater to the structure and thus it is fully utilized. Figure 7 shows a typical heater segment from the main ring with the two temperature controllers shown in place.

In summary, with regard to image stability, at least as far as structural stability is concerned, we have confidence that the specifications will be met. The metering truss and the focal plane structure are the two dominant structures affecting image stability. Each has been built, tested and shown to meet its performance requirements. In addition, the heaters and the controllers required for the focal plane structure have been built, tested and are now in the process of being installed on the focal plane structure, as shown in Figure 8.

Optical Achievements

On the subject of image quality, I have mentioned that this is dominated by the optical quality of both the primary and secondary mirrors. The Space Telescope program has, without a doubt, produced the finest large primary mirror anywhere in the world. The mirror has completed polishing, Figure 9, and its final figure quality exceeds its specifications.

Coating the Optics

Upon completing the polishing of the primary and secondary mirrors, (Figure 10) and, having assured the quality of the image, it was necessary to coat the mirrors to assure good photometric efficiency in the ultraviolet region of the spectrum. To this end, a dedicated coating facility was constructed capable of applying an ultraviolet reflecting film on the primary mirror. Such a coating chamber did not exist prior to the Space Telescope program.

After three years of design and construction, the dedicated coating facility was installed and checked out (Figure 11). After many more months of coating development, the primary mirror was coated (Figures 12 and 13) and its reflectivity in the visible was measured. It exceeded the specifications by 10%. The secondary mirror similarly has been coated and its figure quality verified to exceed specifications subsequent to the coating operation. It is nearly certain, now, that the OTA system wavefront quality requirement of $\lambda/20$ will be met as will the top level system performance requirement for $\lambda/15$. The reflectivity requirement at the Lyman-Alpha line (in the ultraviolet) at 1216 angstroms was established at the outset of the program as being a reflectivity of 70%. Typically, coatings of that time had been designed to achieve 72 or 73% reflectivity and that was about all that was expected from the primary mirror. In fact reflectivity was measured at 78% and was extremely uniform (within a percent or two) over the entire mirror surface. The secondary mirror, which was coated in a more conventional facility, achieved a reflectivity of 73%. Thus the two mirrors in combination will provide an optical throughput in the ultraviolet in excess of the original requirements. The actual reflectivity of each mirror is summarized in Figure 14.

Mounting the Primary Mirror

The challenge, following the completion of polishing and coating the primary mirror, was to mount the mirror in the main ring. This ring must be capable of supporting the weight of the mirror, which is nearly 2,000 pounds, through a shuttle launch and landing. In addition, while operating on orbit in the weightlessness of space, the ring should impart no significant forces or moments to the mirror. If it did through launch, these forces or moments would distort the surface of the mirror and degrade the quality of the image. Thus, a very significant effort was put forth to design and implement a mirror mounting scheme that would induce mirror distortions as close to zero as possible. The entire mounting and assembly operation was conducted in a clean room and tested in a simulated zero "g" environment. That is, the primary mirror was "floated" on a large number of support points rather like a giant bed of nails where each of the nails is spring loaded to exactly support the weight of the mirror above it. In a similar manner, the main ring - the large structural backbone of the telescope - was also supported at a number of points. The mounting hardware which links the primary mirror to the main ring was then installed and similarly off-loaded to simulate the effects of weightlessness while the mounting operation was accomplished. While this operation sounds simple, in fact it took many months to complete because at each step of the way tests were conducted to insure that the mirror was in no way degraded by the assembly operations that had taken place. Several of the steps in assembling the mirror to the main ring are shown in Figures 15, 16, and 17.

This "strain free mount", as the zero "g" simulation is called, was completed early in March of this year, and the final set of optical tests was conducted. These tests proved that the primary mirror indeed was mounted to the main ring securely and that the mounting operation had not degraded the primary mirror in any significant way. The primary mirror still remains the finest mirror in the world and more than adequate to the needs of Space Telescope.

Mounting the Secondary Mirror

Though it is often overshadowed by the primary mirror, the secondary mirror is no less important. While significantly smaller (about 12 inches in diameter) than the primary mirror and weighing much less (28 pounds), it needs to be mounted on a set of actuators which are capable of positioning it in space on command from the ground. It also needs to be mounted in a strain free condition. This mounting operation also has been completed, and the secondary mirror is mounted in its assembly, shown in Figure 18, with the actuators. Tests have shown it to be free of any mechanically induced stresses or strains.

Optical Alignment

Alignment of these two optical elements - the primary and secondary mirrors - is accomplished in orbit using the optical control subsystem, the key element of which is the wavefront sensor. The type of wavefront sensor employed and the philosophy of aligning an optical system in space had not been attempted previously. To prove that the approach used would work, an engineering model of the optical control system wavefront sensor was built (Figure 19) and tested in the laboratory. Test results have shown the sensor to provide error signals which are capable of allowing secondary mirror position errors to be determined. Based on these signals, ground commands can be initiated to reposition the secondary mirror to the precise location required for focus of the telescope. The residual errors associated with this operation have been specified to be less than 1/87th of a wave, root mean square (RMS). Our engineering model tests have proved that the residual wavefront error specification can be met by a system of three white light interferometers and data reduction on the ground. The system designed for Space Telescope has been shown to achieve the required telescope performance.

Fine Guidance Sensor (FGS)

Next to the primary mirror, perhaps the most difficult challenge of all in the Space Telescope program is the design and construction of a set of fine guidance sensors, any one of which is capable of measuring telescope line of sight errors to an accuracy of 0.0028 seconds of arc using a visual magnitude 13 guide star. These fine guidance sensors, shown schematically in Figure 20, have been designed, and some of the hardware has been fabricated or procured. The optical bench (Figure 21), star selector servo system (Figure 22), photomultiplier tubes and the Koesters interferometer prisms have all been built for the first unit. In addition, the fine guidance electronics has been built as an engineering model (Figure 23). The principal task at hand now is to complete the assembly of the first fine guidance sensor, and to subject this assembly to a thorough testing program to insure that it works as a system and provides the required error signals. The very sophisticated computer simulations which have been conducted simulate the function of each element of the fine guidance sensor. These simulations have shown that the system will work and will achieve the accuracy required. This is not to say that completion of FGS development will be routine. The FGS is a complex instrument which will require our best skills and dedication over the next year. I will further address this topic later in this statement.

Summary of Accomplishments

In summary, solutions to each of the major technical challenges identified in the program have been completed or are now nearing completion. All indications are that, at completion, these solutions will be successful in meeting all of the original performance requirements of the Space Telescope.

In terms of image quality - especially in the ultraviolet - performance is expected to be superlative. We are taking precautions to ensure this with special testing prior to shipment to LMSC.

Using encircled energy at the Lyman-Alpha line (1216A^{o}) as a measure of telescope performance, the OTA is predicted to exceed the originally (1977) expected ST performance by a factor of about 4. Indeed, it exceeds the (1974) predicted performance of the 3 meter Large Space Telescope by a factor of more than 2. This comparison is summarized in Figure 24.

RECENT TECHNICAL CONCERNS

Let me consider some of the technical challenges which evolved during the course of the program; that is, those challenges not clearly identified at the beginning of the program. One of these was the problem of designing and building a set of latching mechanisms to enable replacement of science instruments on orbit. In addition, there have been problems associated with the strength of graphite epoxy particularly in the flexure foot of the focal plane structure. The control of contamination - particularly dust particles in the vicinity of the primary mirror - has also been a larger than expected problem. A summary of the status of each of these problem areas is presented below.

Instrument Retention Mechanism (Latch)

In addition to the performance requirements for Space Telescope and the scientific objectives that were established at the outset of the program, a number of requirements to be achieved by the program not relating specifically to the science but relating to the provision of a long term national facility were also set forth. One such requirement was to provide a facility capable of technical update and repair on orbit. Thus, each of the scientific instruments and a significant number of the electronic boxes would be capable of replacement on orbit. As noted previously the scientific instruments have very stringent requirements in terms of their alignment relative to the optical axis of the telescope facility. In addition, it is necessary to provide a telescope facility capable of accepting a wide variety of instrumentation, not just those built for the first flight. Thus, the focal plane structure and its associated latches for the scientific instruments, need to accommodate the widest possible spectrum of scientific instrumentation.

This requirement imposes the need to design a set of general purpose latching mechanisms capable of achieving alignment requirements smaller than one tenth of a thousandth of an inch, of supporting the weight of an instrument (700 pounds) through a shuttle launch, and of accommodating wide changes of temperature on the instruments. These requirements need to be met without distorting the focal plane structure and without significant heat flow to or from the science instruments. These sometimes competing design requirements coupled with the need for strength and stiffness in a large structure resulted in a very complicated set of latches. At present, these challenges are mostly behind us. The latches are designed, and a number of each configuration have been built. Testing to date has been successful. With completion of testing, the modifications to improve frictional characteristics is underway and completion of assembly of all latches is not anticipated to result in any additional problems. Some of the latches are shown in Figures 25, 26, 27.

Focal Plane Structure

This is the first program which has extensively used graphite epoxy in strength critical structural applications. While this material has been used in the past for optical benches, and while Perkin-Elmer has used it many times for such applications, such use required stability and stiffness, but rarely strength. In the case of the focal plane structure, we are dealing with an optical bench capable of supporting five scientific instruments and three fine guidance sensors weighing a total of over 4800 pounds. Thus, in the Space Telescope the focal plane structure has to support all that hardware through a shuttle launch and landing. As a result, strength becomes a critical parameter in the design of the focal plane structure. The region of the focal plane structure known as the flexure (Figure 28) is a blade of graphite epoxy which interfaces the focal plane structure to the aft face of the main ring. This blade takes the entire weight of the structure, the fine guidance sensors and the scientific instruments. The lower section of this element, called the flexure foot, was strength tested and failed when subjected to the shuttle loads. After a very extensive design analysis activity a redesigned flexure foot was built, tested and was proven successful. That repair has now been implemented on the flight focal plane structure, and is shown close up in Figure 29. Each of the flexure feet are now sandwiched in a titanium fitting known as a titanium boot. The boot is bolted through the flexure and, in addition, is bolted to the main ring thus providing the reinforcement necessary in the critical region of the flexure foot. Tests have shown that the flexure feet and the flexures are adequately strong. Again, that problem is behind us and the necessary repair has been implemented.

Contamination

A remaining concern relates to contamination in the form of dust particles and hydrocarbon contamination on the primary mirror. It should be noted that the primary mirror has been kept in a clean room ever since it was coated in December of 1981. Further, that clean room is well maintained and the air quality is monitored continuously. Nonetheless, no clean room is perfectly clean and some dust particles are always present. Therefore, over a period of time, an exposed surface will gather dust even in a clean room; and the primary mirror proved to be no exception. This has proved to be the case even though the mirror has been covered while it was not actually being worked on, e.g., interferometric testing. In the intervening year and a half since the mirror was coated, dust particles have settled on the mirror surface. The question now is what to do about that. Is it acceptable to leave as is or should some attempt be made to clean the mirror? It was recognized that any attempt to clean the mirror has an attendant risk of damage to the mirror coating. Significant analyses have been recently conducted. Samples of the dust have been gathered and photographs of the dust particles have been made in order to count their number and to measure their size. Preliminary conclusions are that in the ultraviolet regions of the spectrum the primary mirror is marginally acceptable as is. In the visible regions of the spectrum the primary mirror will be adequate as it is at this moment.

The concern remains, however, that the primary mirror will accumulate more dust before the Space Telescope is launched. Thus some performance margin is needed to accommodate the additional dust buildup which is inevitable between now and the launch date. Perkin-Elmer is, therefore, planning a cleaning activity which will be conducted as late as possible, probably in the summer of 1984, and will result in the removal of a significant portion (but not all) of the dust particles on the mirror. The cleaning mechanism to be used is currently envisioned as a benign operation in which the dust is blown with clean dry air or filtered nitrogen and simultaneously vacuumed away with a vacuum hose. Tests to date have shown this approach to result in a successful removal of small dust particles. A proper cleaning fixture needs to be designed and fabricated between now and next summer. The cleaning operation would be conducted with the mirror placed upside down so that no hardware has to be supported above the primary mirror with the risks attendant to that operation. Measurements have shown the dust at this moment obscures no more than two tenths of 1 percent of the primary mirror surface.

In addition, reflectivity measurements of witness mirrors placed and maintained near the primary mirror at all times have shown no evidence of molecular contamination. Due to the significance in the UV spectrum of this type of contamination, however, we are considering the advisability of direct measurements on the primary mirror surface. Such contamination would be significantly more difficult to remove, and more damaging in its effect. We do not expect any hydrocarbon contamination but we will continue to monitor for it and test as appropriate, to ensure the ultraviolet throughput is guaranteed at launch.

Based on the above data, we are confident that by the time the OTA is shipped from Perkin-Elmer it will be a clean telescope with a high performance set of optics. These optics will essentially not be degraded by the assembly process, by handling in the plant or by any contamination that may have resulted in the intervening years.

FGS Interferometer

During the Phase B studies in 1973-75, an interferometric form of fine guidance sensor was selected as being the best way of achieving sensitivity to pointing errors as small as 0.001 arc second. This form of sensor was built and demonstrated in the laboratory by Perkin-Elmer in 1976.

Recently some of the flight interferometers tested exhibited anomolous transfer characteristics. Since we had previously shown the interferometer scheme to work, we were sure that the anomaly was peculiar to that particular test and not generic to all interferometric fine guidance sensors. After thorough analysis and further testing, the problem has been isolated to the manufacture and test methods employed to make the interferometer prisms. These methods have been revised, and those prisms in the laboratory which were faulty are being reworked.

While we are confident that there are no known fundamental design problems in the FGS, additional effort will be required in resolving Koesters prism fabrication and assembly difficulties. The FGS assembly, alignment and testing will present a formidable effort requiring the application of our highest skilled optical work force.

FACTORS AFFECTING PROGRAM GROWTH

In previous remarks to the committee, we expressed optimism that we could deliver the OTA in December 1983, within the cost projected at that time. This confidence was based on the quantity of critical hardware already on hand, and the progress we had made to that point in meeting technical challenges on the program, including especially the successful completion of polishing and coating the primary mirror.

However, as we also pointed out during last year's hearing, almost all hardware on the OTA is state-of-the-art, and some very difficult tasks still lay ahead.

As you know, we have had to extend the OTA delivery date by almost a year, and request additional funds from NASA to carry this program to completion. It is reasonable to ask, "what happened to disrupt our plans and preclude the shipment of OTA in December 1983."

Although many factors were involved, basically our problems resulted from a combination of our underestimating technical challenges, and the cumulative effect on funding shortages resulting from the inability to predict, in sufficient time to meet the budget cycle, the cost of meeting these technical challenges. This funding shortfall, in turn, resulted in elimination of development testing, cut backs on critical support hardware, interruption in certain development efforts, and in general, operational inefficiencies.

At a time when we should have been increasing program manpower to address technical problems and changes in work scope, we had to actually reduce manpower to conform with budget estimates made two years earlier.

Figure 30 notes some of the effects of funding constraints on program activities, and outlines other factors which contributed to program growth over the life of the program. These factors are:

INFLATION

Our cost projections were seriously affected by inflationary pressures. Whereas our approved quoting rates for labor contained approximately 5% escalation, general economic conditions during late 1970's and early 1980's forced our actual labor costs up at a rate significantly higher than the rates used to estimate program labor costs. Likewise, costs for materials escalated at even higher rates. Figures 31 and 32 address this factor.

SUCCESS ORIENTED APPROACH

The approach to the OTA program was success oriented. That is, in our program planning, very little schedule margin was allowed for problems or unknowns, and the amount of funds held as "reserves" was obviously inadequate.

TECHNICAL PROBLEMS

Like any development program, the OTA has experienced technical problems which contributed to program growth. Major challenges are summarized in Figure 33 and were discussed previously in this report.

PROGRAM CHANGES

Although program changes are common in development programs like the OTA, the number of changes resulting from previously discussed challenges and problems have been significantly higher than expected.

INTERFACE - REDEFINITION

OTA interfaces, particularly as influenced by the Space Transporation System (STS) flight experience resulted in significant schedule and cost impacts to the program.

MANAGEMENT IMPROVEMENTS

By December 1982, it became apparent that the December 1983 OTA delivery could not be supported. Consequently, Perkin-Elmer and NASA implemented an exhaustive effort to critically review all program activities. This effort included a re-examination of our management techniques and revising our approach to a number of crucial program areas such as Development Hardware, Test Programs, and Operational Support (especially Program Spares). This comprehensive analysis of the program disclosed certain deficiencies for which corrective actions have been taken. Figure 34 summarizes these actions. We placed particular emphasis on the following areas:

ORGANIZATION

There was an obvious need to strengthen the OTA organization. During the summer of 1982, Perkin-Elmer hired Mr. Don Fordyce as our new Program Director for OTA. His successful experience in managing space programs, in both industry and government, immediately contributed to an improvement in overall leadership for the OTA program. This addition significantly enhanced our ability to communicate with NASA management concerning program progress, concerns and resource requirements.

Program audits conducted earlier this year revealed the need to further strengthen the OTA project team, and as a result, the following actions were implemented:

- o We restructured the program to strengthen the OTA Program Office by adding two Deputy Program Directors, one for the Optical Telescope Assembly and one for the Fine Guidance System/Optical Control System. Both Deputy Directors have been involved on the OTA program since its inception.
- o We also named an Assistant Program Director - Engineering, to coordinate day-to-day engineering activities across the program.
- o The former Deputy Program Director - OTA, was appointed Chief Engineer for the OTA program and Director of Engineering for the Space Science

Division. His charter is to provide overall technical guidance for the program, and increase focus on OTA within the Space Science Division.

- o We staffed and colocated subsystem teams for Fine Guidance System/Optical Control Sensor (FGS/OCS), Primary Mirror Assembly/Secondary Mirror Assembly (PMA/SMA), Focal Plane Assembly (FPA), Ground Support Equipment (GSE), and Special Test Equipment (STE).
- o We implemented a staffing buildup to increase manpower, especially in critical areas.

These changes have resulted in a more cohesive effort across the program, and improved coordination both internally at Perkin-Elmer, with NASA, and the associate contractor.

Organization charts for Perkin-Elmer's Optical Group, Space Science Division and ST/OTA follow as Figures 35, 36, and 37.

PROGRAM CONTROLS

Our joint investigation with NASA clearly indicated deficiencies in the area of program controls. Improvements were needed to increase program visibility at all levels of management and to avoid surprises by improving the timeliness and quality of the information generated on program status.

To further strengthen the program team and provide for greater accountability in the area of cost and schedule, more frequent reviews were established at all levels of the program. These reviews range from twice daily meetings at the level of task leaders, daily meetings with the Division Manager, twice weekly meetings with the Executive Vice President, and quarterly reviews with the Board of Directors.

The OTA Program Office was strengthened by the addition of six Performance Measurement specialists, each responsible for maintaining the critical review of milestones and cost for each major subsystem. Also, six Schedule Planners were added to monitor and maintain the overall system, and individual subsystem schedules. To enhance our scheduling skills, Perkin-Elmer procured a computerized scheduling system to provide OTA program management with real time response to schedule workarounds/impacts. These efforts will strengthen the work package system used on the OTA program by providing for enforcement of cost and schedule accountability and reporting by all levels of managers and team leaders.

FACILITIES AND GSE/STE

As the program proceeded into the hardware assembly, integration and test phase, we recognized that greater emphasis needed to be placed on allocation of specialized facilities and the availability of support equipment. We have, therefore, allocated 5,000 square feet of additional clean room facilities to OTA for these purposes.

A team of senior Perkin-Elmer technical personnel conducted an independent technical audit of Ground Support Equipment and Special Test Equipment. As a result, a number of new equipment items were identified, the design of some items was simplified, and some items were eliminated. To minimize schedule impact, a decision was made to subcontract fixtures and dollys, which Perkin-Elmer had formerly planned to do in-house. Also NASA assumed responsibility for the OTA Shipping Container. The net outcome of the audit was that NASA approved Perkin-Elmer's recommendations calling for additional funds for equipment necessary to improve the handling, transporting, aligning and testing of the OTA hardware. Subsystem teams responsible for all GSE/STE activities were assembled and are working to assure that GSE/STE plans and hardware are available to fully support the OTA and FGS/OCS program requirements.

SCHEDULE

Perkin-Elmer developed forecasts in December 1982/January 1983 which although high in technical and schedule risks, could have resulted in OTA delivery in June 1984. Subsequent adoption of recommendations made by Perkin-Elmer to reduce FGS development risk, and the addition of NASA directed thermal vacuum bakeouts to reduce risks of molecular contamination resulted in the current OTA ship to LMSC date of November 1, 1984. The current OTA schedule at the summary level is attached as Figure 38.

SUMMARY

Throughout the OTA development activities, adherence to the original technical specifications has been maintained; not one of the original requirements has been reduced. The scientific community was delighted to learn of the excellence of the primary mirror. We anticipate continuing such achievement in support of the very important science mission of Space Telescope.

The schedule slippage encountered has been the result of two basic reasons: technical problems - nearly every OTA subsystem presses the state-of-the-art; annual fiscal constraints, which restrain the ability to overcome technical difficulties. Attendant to these difficulties and slippages has been an increase in program cost.

There remains an acute awareness of the difficulties and importance of the ST program. We are working to a detailed plan which should require little, if any, future modification. Almost all of the flight hardware is in-house and final assembly and test are underway. We haven't always been in a position to anticipate the unexpected and our response, on occassion, may have been slower than would have been preferred, but Perkin-Elmer is now in a position to solve any problems which might arise. The changes in organization, staffing, and program controls have greatly benefitted the Space Telescope program. Challenges still remain ahead but we are dedicated to deliver the best astronomical telescope, meeting all the original program requirements, ever built.

PERKIN-ELMER

SPACE TELESCOPE PERFORMANCE REQUIREMENTS

1. OPTICAL PERFORMANCE SYSTEM WAVE FRONT ERROR	$\lambda/20$ RMS @ 632.8 nm; UP TO 10 HOURS AUTOCORRELATION LENGTH $\geq$ 0.125 GAUSSIAN, 0 TO 20 CYCLES/PUPIL
2. SPECTRAL RANGE	120 nm - 1 mm
3. APERTURE/SYSTEM f/NO.	2.4 METER, f/24
4. CENTRAL OBSCURATION	14% OF APERTURE AREA (MAXIMUM)
5. FIELD OF VIEW (SCIENCE)	18 ARC-MIN (DIAMETER)
6. FAINT OBJECT SENSITIVITY • 50^0 OF SUN • 70^0 OF EARTH • 15^0 OF MOON	OBJECTS M_V 27 OR BRIGHTER EXTENDED SOURCES M_V 23/ARC-SEC (MAXIMUM INTEGRATION TIME OF 10 HOURS)
7. POINTING STABILITY	0.007 ARC-SEC (M_V 13 TARGET, 400-800 nm) 0.21 ARC-SEC/SEC SOLAR SYSTEM TRACKING
8. REFLECTIVITY (MINIMUM)	85% @ 632.8 nm 70% @ 120 nm
9. DYNAMIC SUSCEPTIBILITY (OTA)	> 18 Hz

PERKIN-ELMER

OTA PROGRAM STATUS AND OVERVIEW

AS WE VIEWED THE OTA PROGRAM AT ITS OUTSET IN 1977, THE SIX TOUGHEST TECHNICAL CHALLENGES WERE

1) STABILITY OF THE PRIMARY MIRROR TO SECONDARY MIRROR SPACING TO WITHIN 3 μM OVER A 24-HOUR PERIOD

2) 0.003 $\widehat{sec}$ STABILITY (0.5 μM LATERAL IMAGE DISPLACEMENT AT THE F / 24 FOCUS) OVER A 24-HOUR PERIOD

3) λ/ 20 SYSTEM WAVEFRONT ERROR, IMPLYING A PRIMARY MIRROR FIGURE OF λ/ 70 AND A SECONDARY MIRROR FIGURE OF λ/ 100

4) REFLECTIVITY OF EACH MIRROR ABOVE 70% AT 1216 $\overset{0}{A}$

5) ALIGNMENT ON-ORBIT USING OCS SENSORS TO WITHIN λ/ 87 RMS

6) 0.0028 $\widehat{sec}$ RMS FGS NOISE EQUIVALENT ANGLE ERROR, ON M_V 13 STAR.

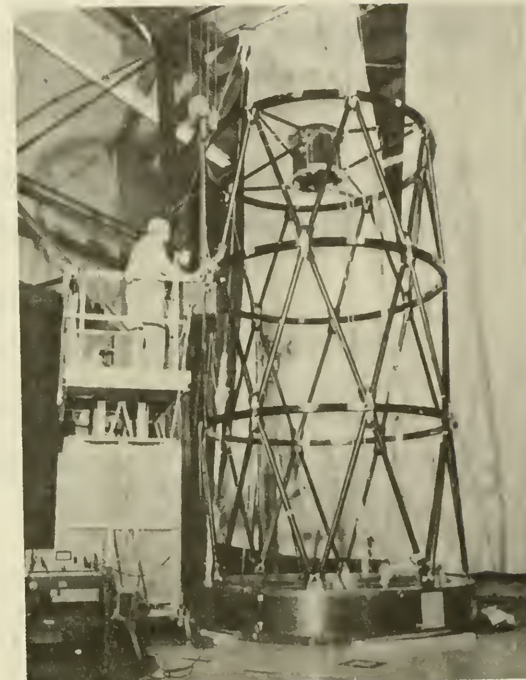
Figure 2

PERKIN-ELMER

TECHNICAL PROGRESS

A PRINCIPAL SCIENTIFIC OBJECTIVE OF SPACE TELESCOPE IS THE OBSERVATION OF VERY FAINT OBJECTS. THIS REQUIRES VERY LONG "EXPOSURE" PERIODS (TO USE A PHOTOGRAPHIC ANALOGY) LASTING UP TO 24 HOURS IN SOME CASES. THE PRESERVATION OF IMAGE QUALITY FOR SUCH LONG OBSERVATION TIMES REQUIRES THAT THE OBSERVATORY STRUCTURE BE VERY STABLE EVEN IN THE PRESENCE OF CHANGING TEMPERATURES.

THE METERING TRUSS IS A 200" LONG STRUCTURE WHICH MUST POSITION THE SECONDARY MIRROR IN EXACTLY THE CORREST POSITION WITH RESPECT TO THE PRIMARY MIRROR, TO AN ACCURACY OF LESS THAN 1/10 OF A THOUSANDTH OF ONE INCH.



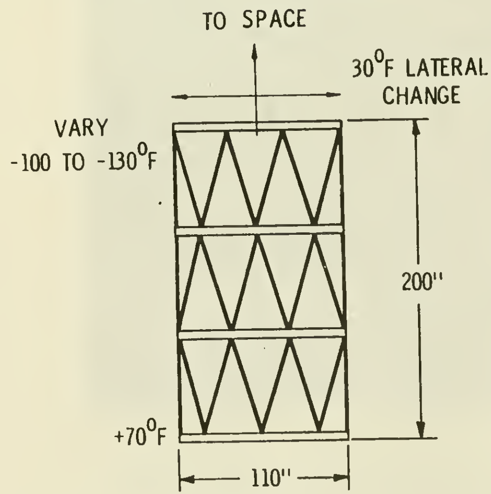
OG 138-82

Figure 3

PERKIN-ELMER

ACHIEVEMENT SUMMARY
OTA METERING TRUSS STRUCTURE
"MEASURED PERFORMANCE MET/EXCEEDED ALL REQUIREMENTS"

TEST ENVIRONMENT



WEIGHT - 250 POUNDS
MATERIAL - GRAPHITE T300/T50 EPOXY 934
STIFFNESS - 25 Hz (1st MODE)
PASSIVE THERMAL CONTROL

TESTING RESULTS

		MEASURED	REQUIREMENTS
• PRIMARY TO SECONDARY	=	1.8μ	3μ (0.00012 IN.)
• DECENTER	=	2.79μ	10μ (0.0004 IN.)
• TILT	=	1.18 $\widehat{SEC}$	2 $\widehat{SEC}$

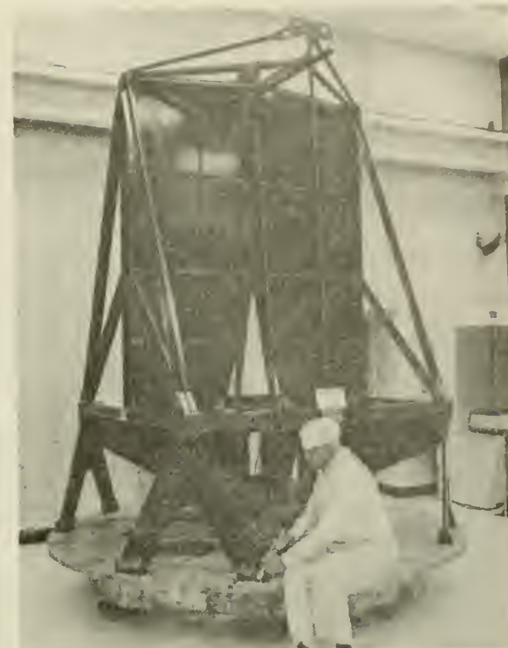
Figure 4

PERKIN-ELMER

FOCAL PLANE STRUCTURE

THE FOCAL PLANE STRUCTURE MUST SUPPORT AN ARRAY OF SCIENTIFIC INSTRUMENTS AND FINE GUIDANCE SENSORS AND PRESERVE THEIR RELATIVE ALIGNMENT – TO ACCURACIES ON THE ORDER OF 1/10 OF A THOUSANDTH OF AN INCH.

ALL OF THESE REQUIREMENTS FOR STRUCTURAL STABILITY HAVE DRIVEN US TO SELECT GRAPHITE FIBRE REINFORCED EPOXY (GRAPHITE EPOXY) AS THE PRINCIPAL STRUCTURAL MATERIAL. THIS MATERIAL HAS THE HIGHLY DESIRABLE PROPERTIES OF VERY LOW EXPANSION COEFFICIENT, LOW WEIGHT AND HIGH STIFFNESS. HOWEVER, IT IS A RELATIVELY NEW MATERIAL, THAT IS NOT WELL CHARACTERIZED IN TERMS OF ITS STRENGTH. OTA HAS ENGAGED IN SIGNIFICANT DEVELOPMENT WORK WHICH HAS ADVANCED THE TECHNOLOGY OF DESIGN AND STRENGTH ANALYSIS USING COMPOSITE MATERIALS.

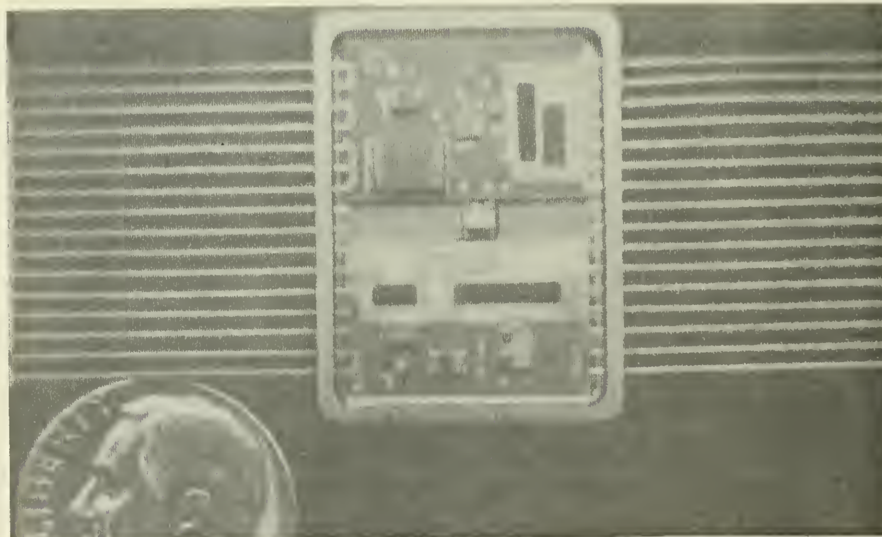


OTD 2491-81

Figure 5

PERKIN-ELMER

TEMPERATURE CONTROL



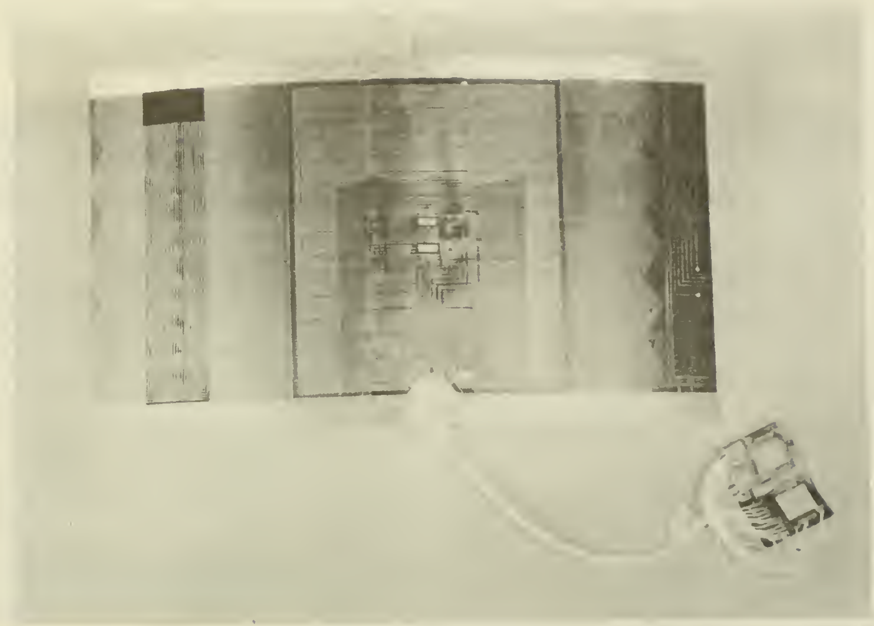
OG 0160-81

ALSO IN THE QUEST FOR EXTREME STABILITY, THE OTA EMPLOYS A LARGE NUMBER OF TEMPERATURE CONTROLLED HEATERS. THESE ARE ESPECIALLY IMPORTANT AROUND THE PRIMARY MIRROR, ON THE FOCAL PLANE STRUCTURE AND IN THE FINE GUIDANCE SENSORS. IN ORDER TO PROVIDE TEMPERATURE CONTROL TO WITHIN 0.1°F, WITHOUT WASTING ELECTRICAL POWER, TO A LARGE NUMBER (OVER 700) OF HEATER ZONES A STATE-OF-THE-ART HYBRID ELECTRONIC CONTROLLER WAS DEVELOPED. THESE TINY COMPONENTS, ABOUT THE SIZE OF A BOOK OF MATCHES, ALLOW THE CONTROLLER TO BE PLACED WITH ITS HEATER AND IS NEARLY 100% EFFICIENT IN TERMS OF POWER CONSUMED. MORE THAN 1000 SUCH CIRCUITS HAVE BEEN BUILT FOR THE OTA. AS WELL AS BEING EFFICIENT USERS OF POWER, THESE CONTROLLERS DRAMATICALLY REDUCE THE AMOUNT OF WIRE NEEDED IN THE THERMAL CONTROL SYSTEM.

Figure 6

PERKIN-ELMER

TEMPERATURE CONTROLLER

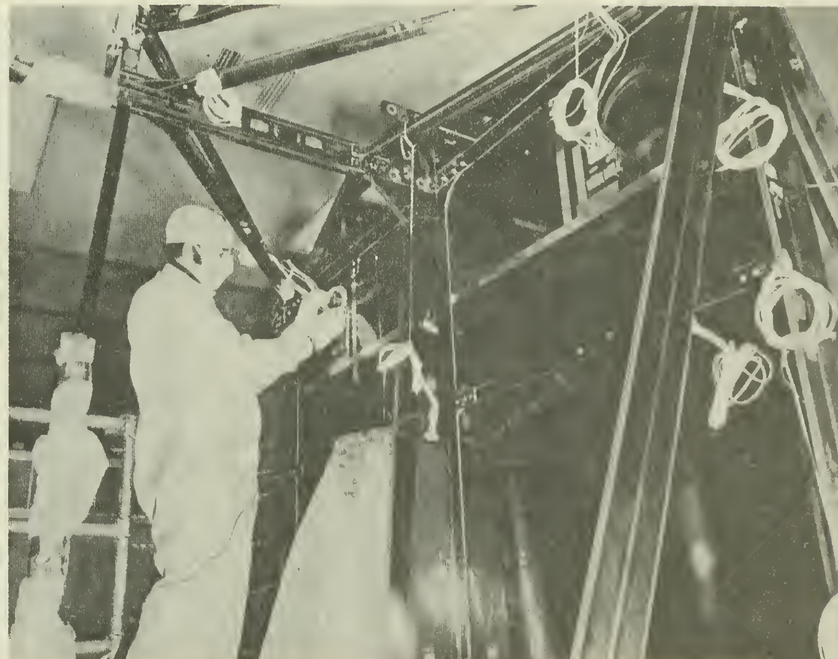


OG 1044-82

Figure 7

PERKIN-ELMER

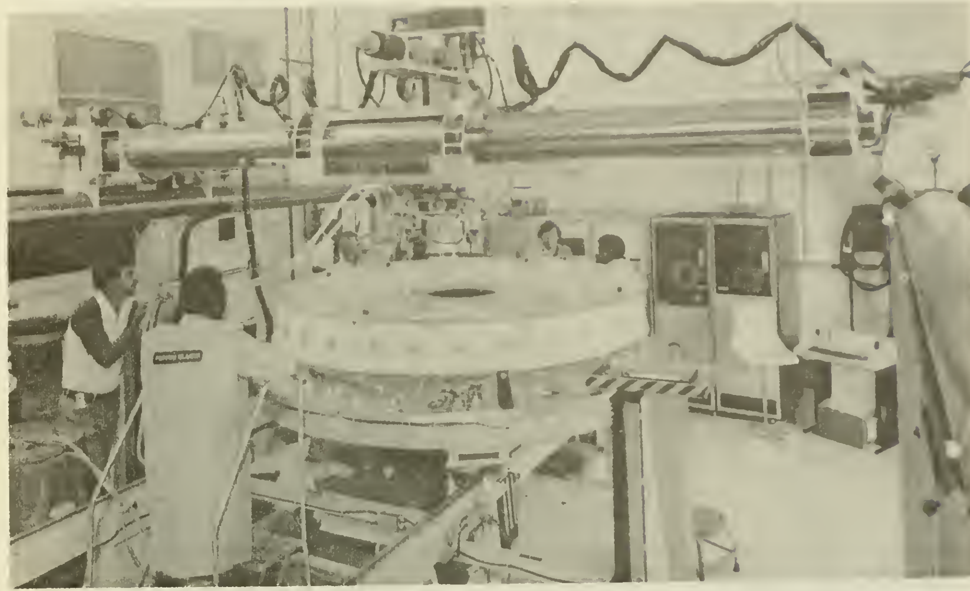
FOCAL PLANE STRUCTURE – HEATER INSTALLATION



OG 075-83

Figure 8

PERKIN-ELMER



OG 1539-80

SPACE TELESCOPE PROGRAM (OTA) HAS PRODUCED THE FINEST MIRROR OF ITS SIZE ANYWHERE IN THE WORLD. SO NEARLY PERFECT IS THE MIRROR SURFACE THAT IF ITS DIAMETER WERE SCALED UP TO THE WIDTH OF THE CONTINENTAL U.S., NO HILL OR VALLEY WOULD DEPART FROM THE IDEAL SURFACE BY MORE THAN ABOUT 2½ INCHES.

MIRROR SMOOTHNESS IS VERY IMPORTANT TO TELESCOPE PERFORMANCE IN THE ULTRAVIOLET REGION OF THE SPECTRUM – WHERE MOST OF THE SCIENTIFIC INTEREST IS. IN ORDER TO ACHIEVE THE SMOOTHEST POSSIBLE SURFACE, SPECIAL TECHNIQUES WERE DEVELOPED TO PERFORM ALL POLISHING BY A COMPUTER CONTROLLED MACHINE. NO HAND POLISHING WAS USED WHATSOEVER. A CONVENTIONALLY POLISHED MIRROR COULD NOT APPROACH THE SMOOTHNESS OF THE ST MIRROR.

Figure 9

PERKIN-ELMER

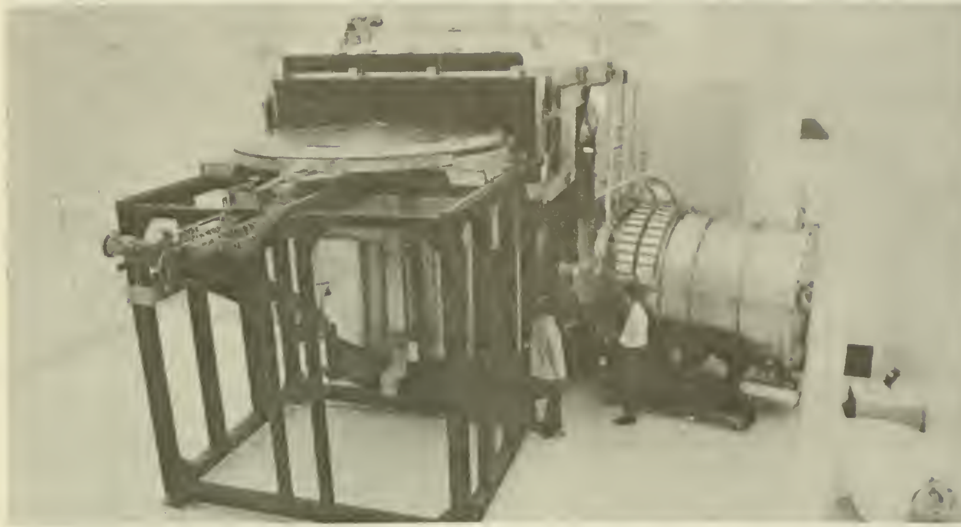
SECONDARY MIRROR POLISHING

OG 2154-80

Figure 10

PERKIN-ELMER

COATING FACILITY



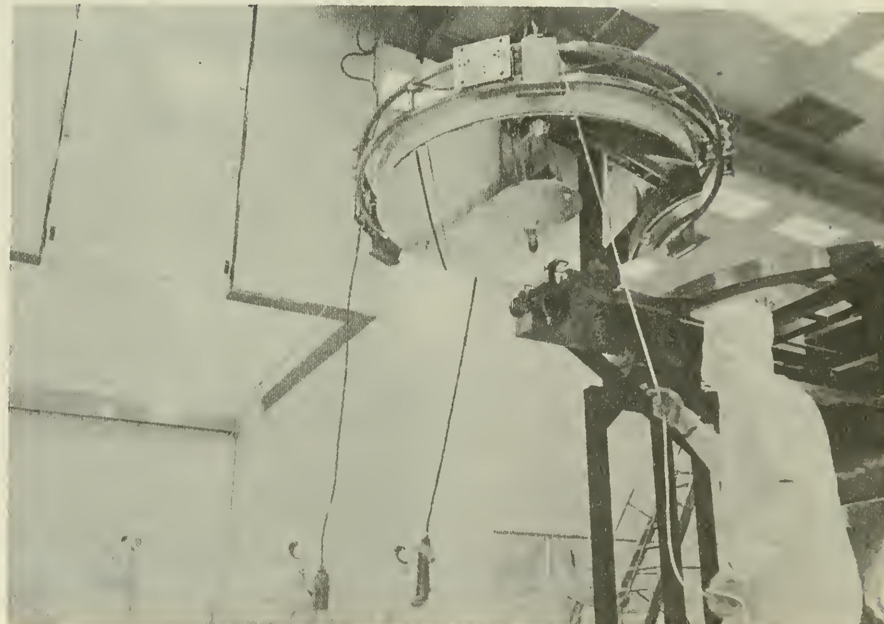
OG 2506-81

IN ORDER TO REALIZE THE MAXIMUM SCIENTIFIC RETURN ON THE INVESTMENT IN THE ST OBSERVATORY ITSELF, THE MIRRORS SHOULD HAVE THE HIGHEST POSSIBLE REFLECTIVITY IN THE ULTRA-VIOLET. IT WAS SHOWN EARLY ON THAT THE HIGHEST REFLECTIVITY WAS ACHIEVED WHEN THE THIN REFLECTIVE COATING WAS DEPOSITED IN A VERY HIGH VACUUM, AT HIGH SPEED AND AT ELEVATED TEMPERATURES (300°F). FURTHERMORE, THE COATING WAS MOST UNIFORM IF THE MIRROR SUBSTRATE WERE ROTATED SLOWLY DURING THE COATING PROCESS. THUS, THE OTA PROGRAM UNDERTOOK THE DESIGN AND CONSTRUCTION OF A SOPHISTICATED COATING CHAMBER, THE LIKE OF WHICH EXISTS NOWHERE ELSE IN THE WORLD. THE CHAMBER IS LARGE ENOUGH TO ACCEPT THE 8 FOOT DIAMETER PRIMARY MIRROR, CAN BE EVACUATED TO A PRESSURE LESS THAN 1 BILLIONTH OF NORMAL ATMOSPHERIC PRESSURE AND CAN ROTATE THE PRIMARY AT 3 RPM DURING THE COATING PROCESS.

Figure 11

PERKIN-ELMER

PRIMARY MIRROR – FOLLOWING COATING ACTIVITY

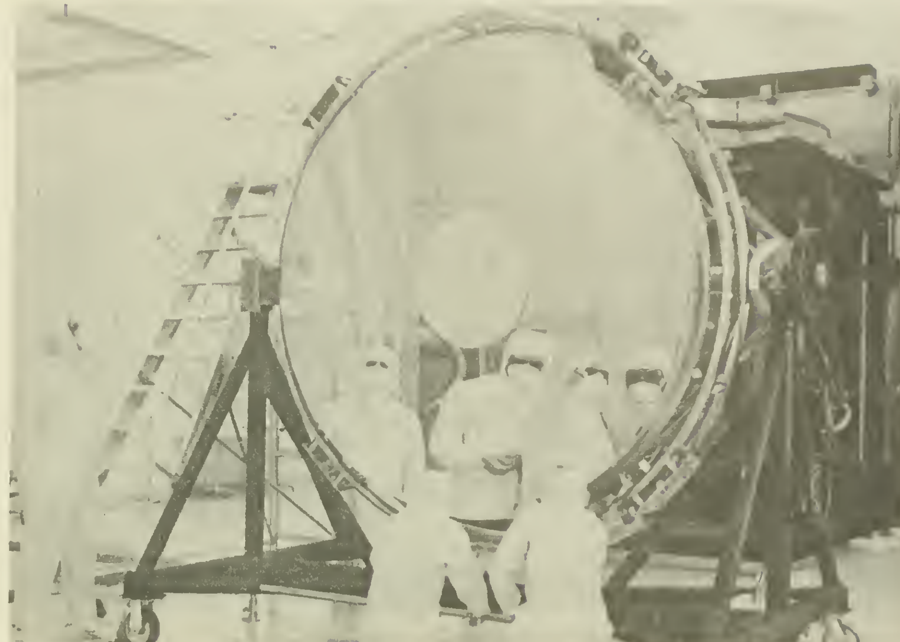


OG 3583-81

Figure 12

PERKIN-ELMER

PRIMARY MIRROR – FOLLOWING COATING ACTIVITY



OG 3700-81

Figure 13

PERKIN-ELMER

REFLECTIVITY

REQUIREMENT	STATUS		
AT 6328Å, R ≥ 85%	6328Å	PRIMARY	89%
		SECONDARY	89%
AT 1216Å, R ≥ 70%	1216Å	PRIMARY	78%
		SECONDARY	73%

Figure 14

PERKIN-ELMER

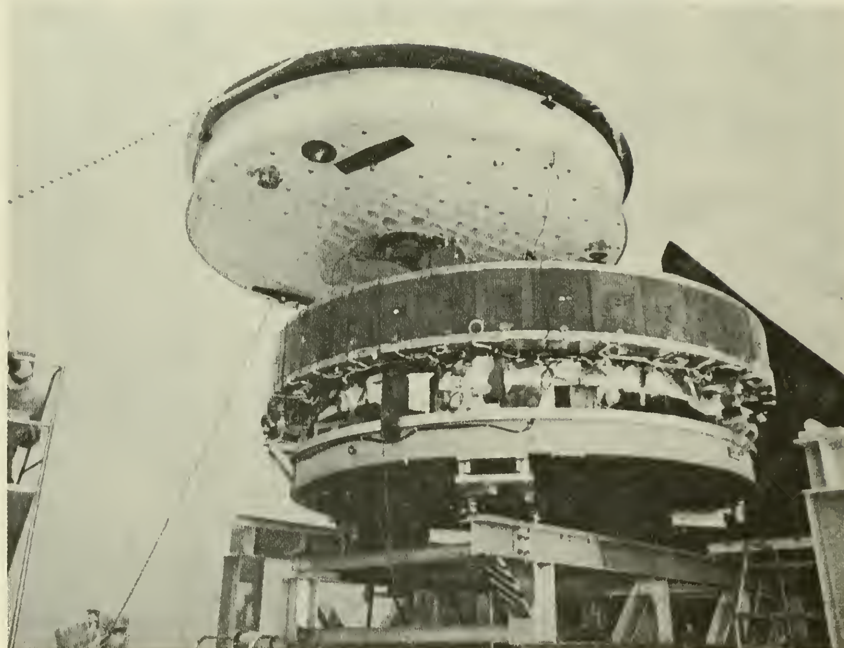
PRIMARY MIRROR – TRANSFER TO MAIN RING

OG 027-83

Figure 15

PERKIN-ELMER

PRIMARY MIRROR – MAIN RING INTEGRATION

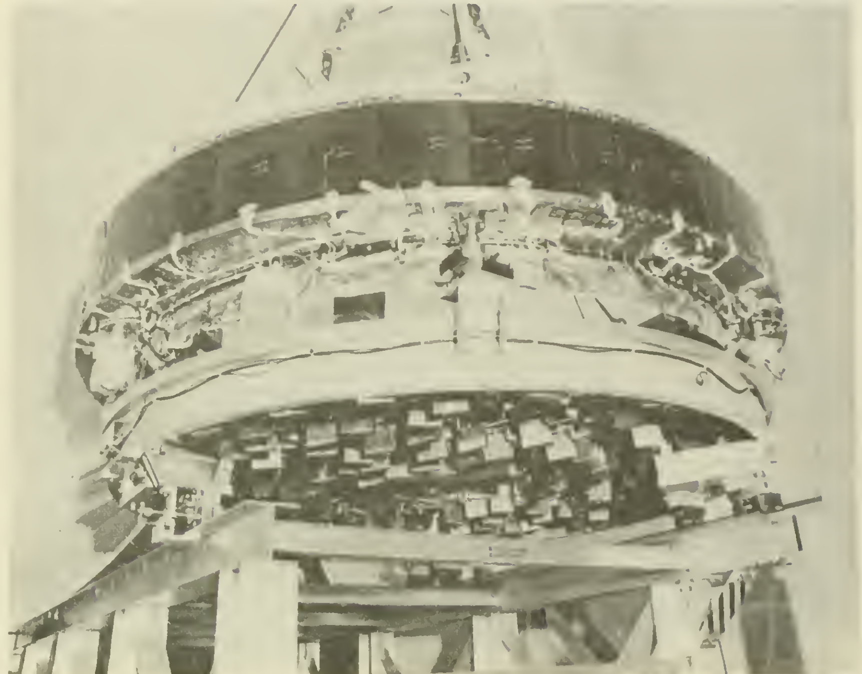


OG 028-83

Figure 16

PERKIN-ELMER

MAIN RING AND METROLOGY MOUNT

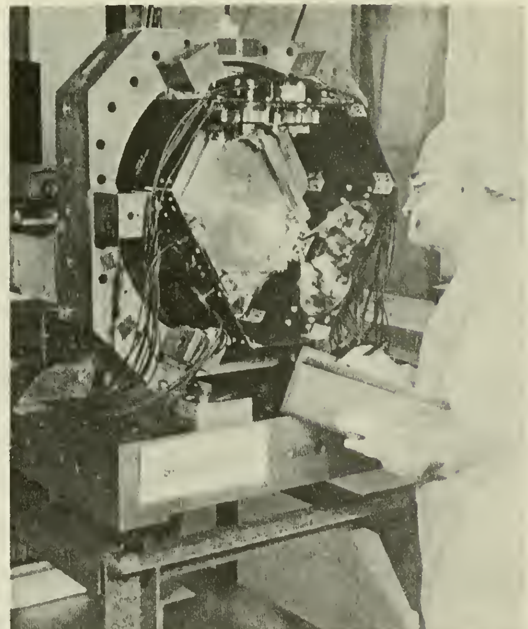


OG 4057-82

Figure 17

PERKIN-ELMER

SECONDARY MIRROR SUBASSEMBLY

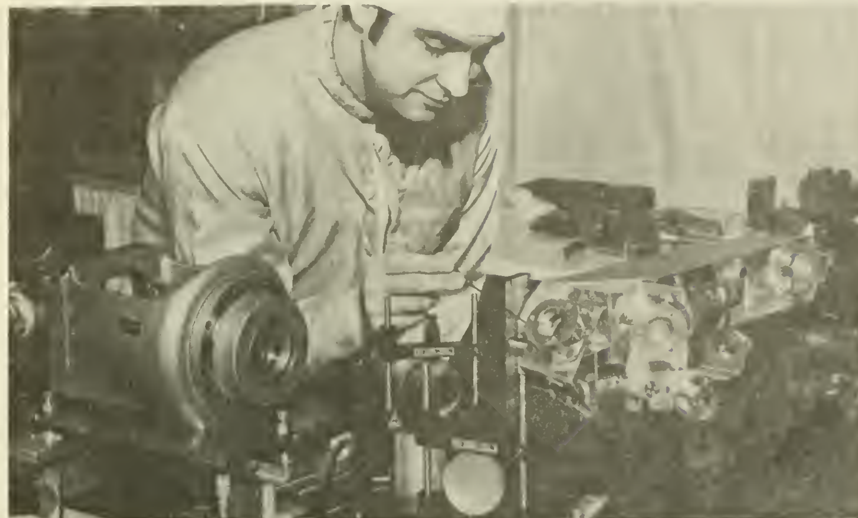


OG 2404-82

Figure 18

PERKIN-ELMER

OPTICAL CONTROL SUBSYSTEM



OG 580-81

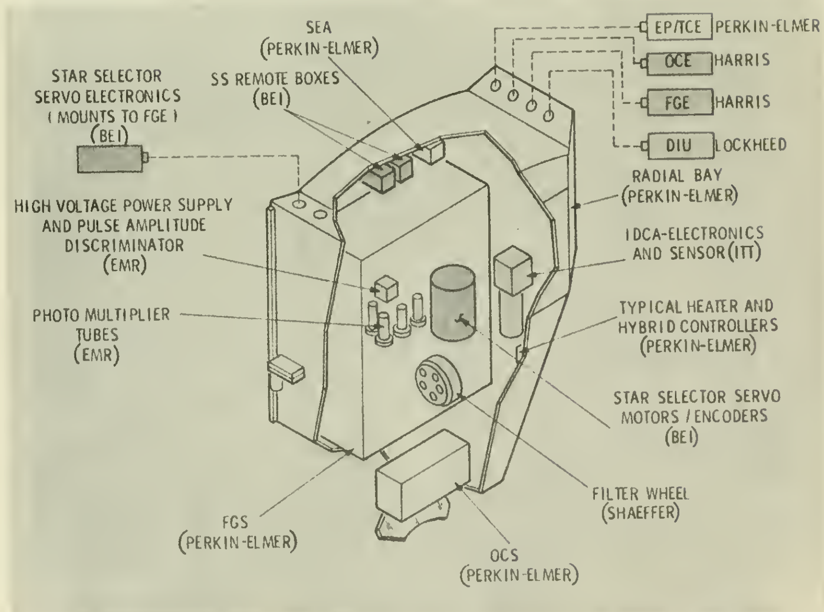
IT WOULD BE INORDINATELY EXPENSIVE (AND MAYBE IMPOSSIBLE) TO ALIGN THE SECONDARY AND PRIMARY MIRRORS TO THE REQUIRED TOLERANCES ON THE GROUND, AND HAVE THEM STAY ALIGNED THROUGH A SHUTTLE LAUNCH AND ORBITAL INSERTION.

TO BRING ABOUT AN INITIAL ALIGNMENT OF THE TELESCOPE SYSTEM AND TO OPTIMZE ITS IMAGE QUALITY IN ORBIT, WE DEPEND UPON THE OPTICAL CONTROL SYSTEM. THIS IS AN ARRAY OF THREE VERY SENSITIVE WHITE LIGHT INTERFEROMETERS AT THE FOCAL PLANE OF THE TELESCOPE. USING A BRIGHT STAR AS A LIGHT SOURCE, THEY TELEMETER TO THE OPERATIONS CONTROL CENTER DATA ABOUT THE OPTICAL ABERRATIONS PRESENT IN THE SYSTEM, AND FROM THESE DATA, ENGINEERS DEDUCE THE REALIGNMENTS NECESSARY AND SEND UP THE APPROPRIATE COMMANDS TO ACTUATORS WHICH REPOSITION THE MIRRORS.

Figure 19

PERKIN-ELMER

FINE GUIDANCE SENSOR



OG 821-83

Figure 20

PERKIN-ELMER

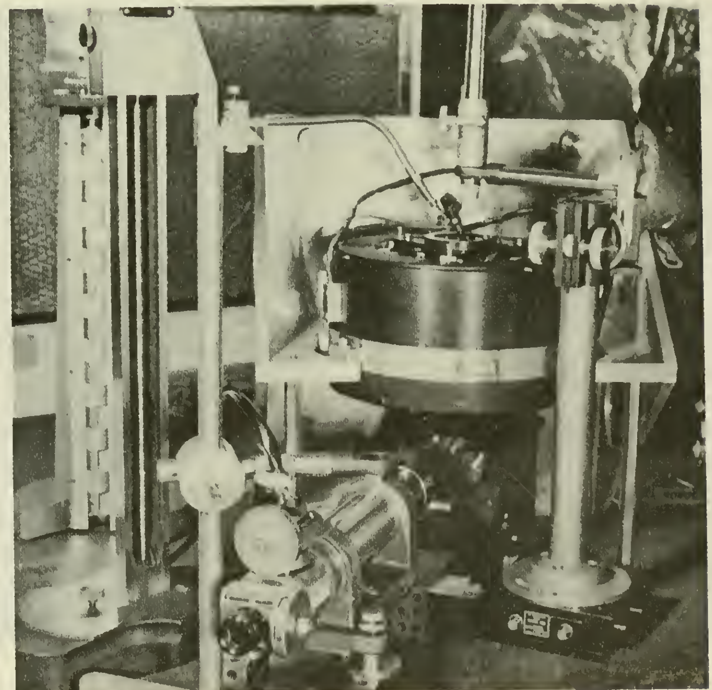
SHIP-SET OPTICAL BENCH ASSEMBLY FOR FINE GUIDANCE SYSTEM

OG 2503-81

Figure 21

PERKIN-ELMER

SETTING OF BORE FIXTURE IN MOTOR ENCODER FOR STAR SELECTOR

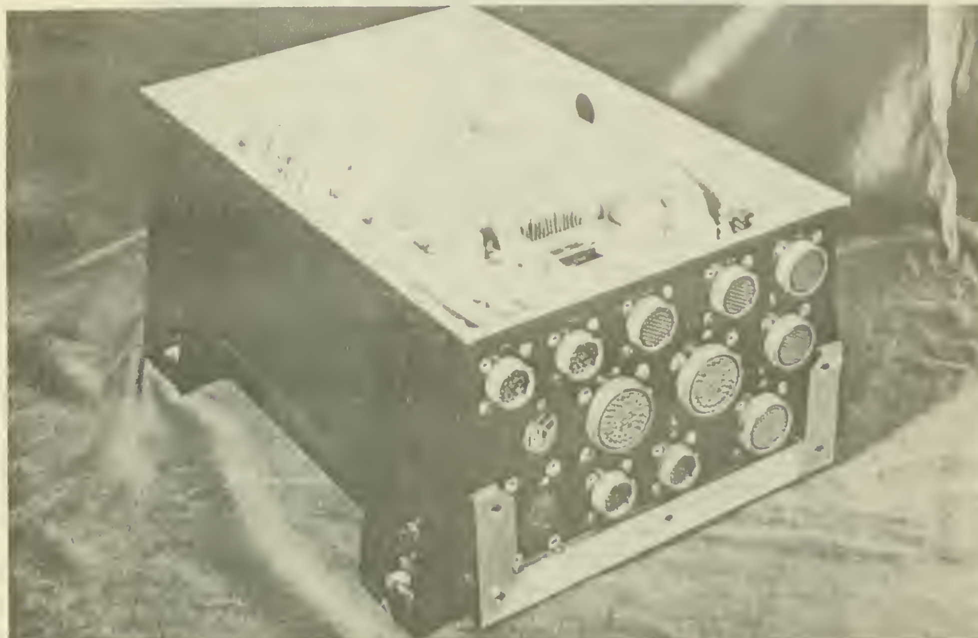


OG 2744-82

Figure 22

PERKIN-ELMER

FINE GUIDANCE ELECTRONICS



OG 0158-81

Figure 23

PERKIN-ELMER

SYSTEM PERFORMANCE IMPROVEMENT

	REFLECTIVITY		PREDICTED ENCIRCLED ENERGY AT 1216Å
	PRIMARY	SECONDARY	
IN 1974, THE 3-METER LARGE SPACE TELESCOPE WAS BASELINED WITH THESE PERFORMANCE GOALS	70%	70%	15%
AT THE OUTSET OF PHASE C/D IN 1977, THE 2.4 METER ST WAS BASE-LINED AND PREDICTED TO HAVE THESE PROPERTIES	70%	70%	15%
NOW, IN 1983, THE ACTUAL ST OPTICS HAVE BEEN MEASURED TO HAVE THESE PROPERTIES	78%	73%	55%

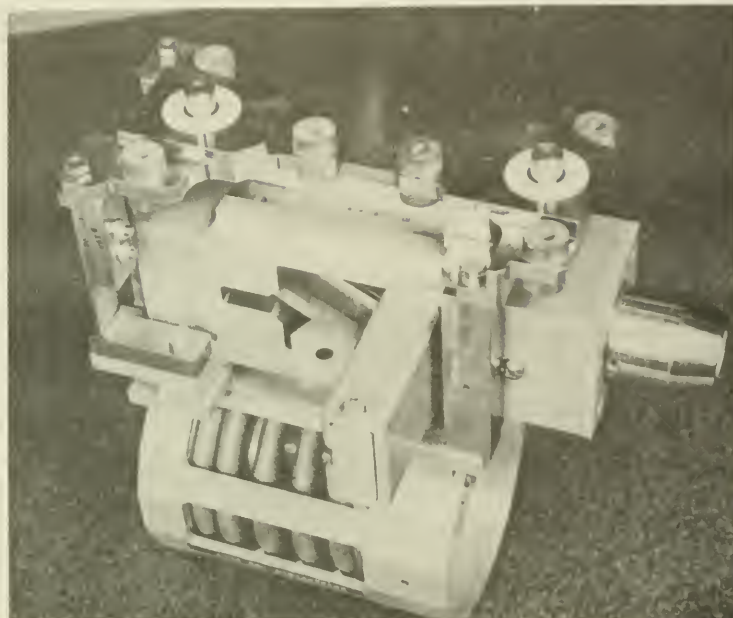
BASED ON THE NUMBER OF PHOTONS AT 1216Å FOCUSED BY THE TELESCOPE THROUGH AN SCIENCE INSTRUMENT APERTURE 0.1 $\widehat{sec}$ RADIUS

TODAY'S ST IS 2.73 TIMES AS GOOD AS 1974'S 3-METER LST AND 4.25 TIMES BETTER THAN PREDICTED AT BEGINNING OF CONTRACT

Figure 24

PERKIN-ELMER

LATCH – POINT B AXIAL PRELOAD HALF

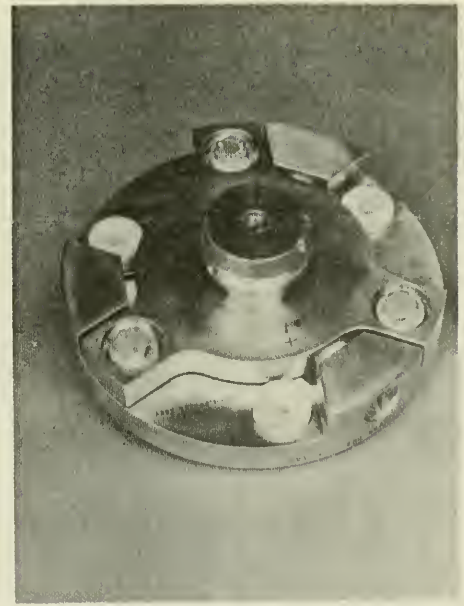


OG 2142-80

Figure 25

PERKIN-ELMER

LATCH – POINT A AXIAL BALL

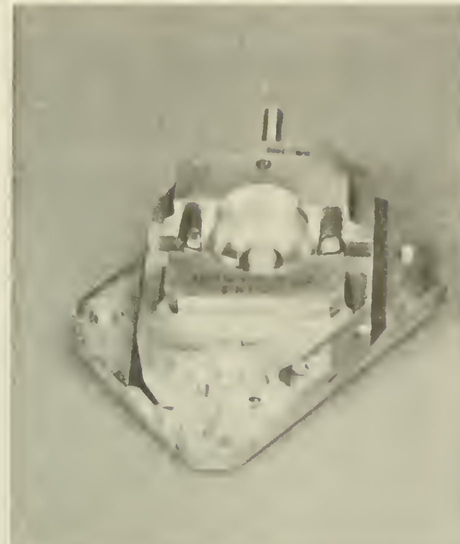


OG 1434-81

Figure 26

PERKIN-ELMER

LATCH – POINT A AXIAL SEAT

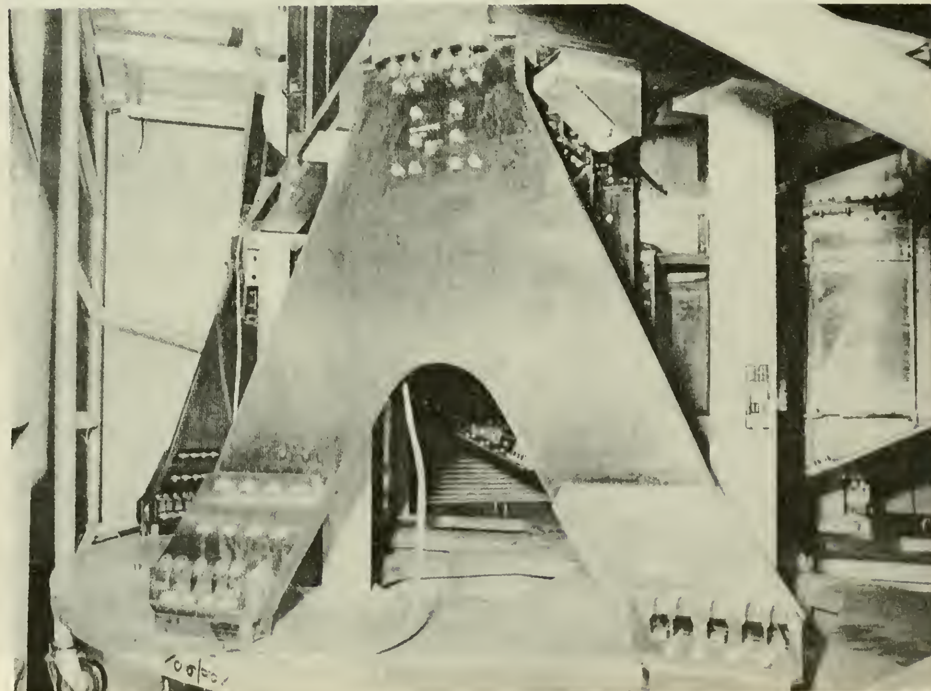


OG 1433-81

Figure 27

PERKIN-ELMER

FOCAL PLANE STRUCTURE FLEXURE



OG 3666-82

Figure 28

PERKIN-ELMER

FPS FLEXURE BOOT

OG 3663-82

Figure 29

PERKIN-ELMER

FACTORS AFFECTING PROGRAM GROWTH

- ECONOMIC CLIMATE (INFLATION / RECESSION)
- SUCCESS ORIENTED APPROACH
- RAPID START UP
- TECHNICAL PROBLEMS
- PROGRAM CHANGES
  - INEFFICIENCY DUE TO LARGE NUMBER OF CHANGES
  - TECHNICAL REDIRECTION
- INTERFACE – REDEFINITION
- FUNDING CONSTRAINTS
  - HIATUS AT SUBCONTRACTORS
  - INEFFICIENT OPERATIONS
  - GREATER DOWNSTREAM COSTS
  - BUILT IN RISK
  - STRETCHED SCHEDULE / LOST SLACK

Figure 30

PERKIN-ELMER

EFFECTS OF INFLATION:

- SPECIFIC IMPACT ON THIS PROGRAM DIFFICULT TO QUANTIFY.
- INFLATIONARY CLIMATE DURING PERIOD OF PERFORMANCE AFFECTED:
  - LABOR COSTS
  - MATERIAL COSTS
  - OVERHEAD COSTS
- RESULT – INCREASED COST OF A MANMONTH ON PROGRAMS.

Figure 31

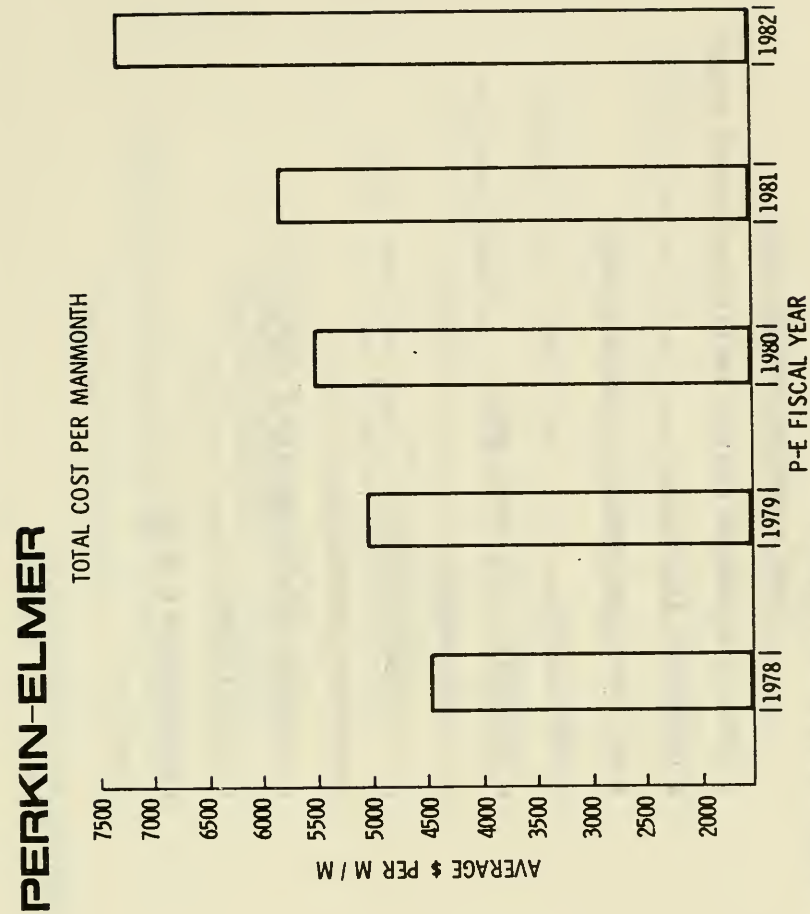

PERKIN-ELMER
TOTAL COST PER MANMONTH
AVERAGE $ PER M / M
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1978
1979
1980
1981
1982
P-E FISCAL YEAR

Figure 32

PERKIN-ELMER

TECHNICAL PROBLEMS CAUSING GROWTH

- FOCAL PLANE STRUCTURE REDESIGN AND RESULTANT THERMAL STUDIES
- LARGE OPTICS FABRICATION
- FGS OPTICAL BENCH REDESIGN TO GRAPHITE-EPOXY
- SHUTTLE LOADS
- STAR TRACKER / RATE SENSOR SHELF
- FGS / PCS CHANGES
- ST ENViRONMENTAL TEST
- FPS FLEXURE MODIFICATION
- INSTRUMENT RETENTION MECHANISM (LATCH)
- FGS BREADBOARD
- HYDRO-CARBON BAKE-OUT
- STE / GSE

Figure 33

PERKIN-ELMER

MANAGEMENT ACTIONS TAKEN

- TWICE WEEKLY OPERATIONS MEETINGS HELD WITH THE EXECUTIVE VICE PRESIDENT, GAYNOR KELLEY.
- SPACE SCIENCE DIVISION ORGANIZATION CHANGES

  DR. JOHN C. RICH – ASSISTANT DIRECTOR, ENGINEERING
  ROBERT W. JONES – SPACE TELESCOPE, CHIEF ENGINEER

  PROVIDES MORE MANAGEMENT FOCUS FOR SPACE TELESCOPE.
- RESTRUCTURED AND STAFFED THE PROGRAM OFFICE

  PAUL C. BRICKMEIER AS DEPUTY DIRECTOR – OTA
  GERALD W. LE BLANC AS DEPUTY DIRECTOR – FINE GUIDANCE SUBSYSTEM / OPTICAL CONTROL SUBSYSTEM

  ADDED SENIOR TECHNICAL AND MANAGEMENT PERSONNEL
- COMPLETED RED TEAM REVIEW OF ALL GSE AND STE AND IMPLEMENTED TEAM RECOMMENDATIONS.
- CONDUCTED FGS TECHNICAL AUDIT BY SENIOR TECHNICAL STAFF FROM P-E, LMSC AND MSFC.
- FGS / OCS ELEVATED IN PROGRAM IMPORTANCE.
- STAFFED AND CO-LOCATED SUBSYSTEM TEAMS FOR FGS / OCS, PMA / SMA, FPA, LATCHES, GSE, STE, ELECTRONICS
- STAFFING BUILD-UP PROGRAM
- ADDED REQUIRED ADDITIONAL CLEAN ROOM FACILITIES

Figure 34

PERKIN-ELMER

OPTICAL GROUP

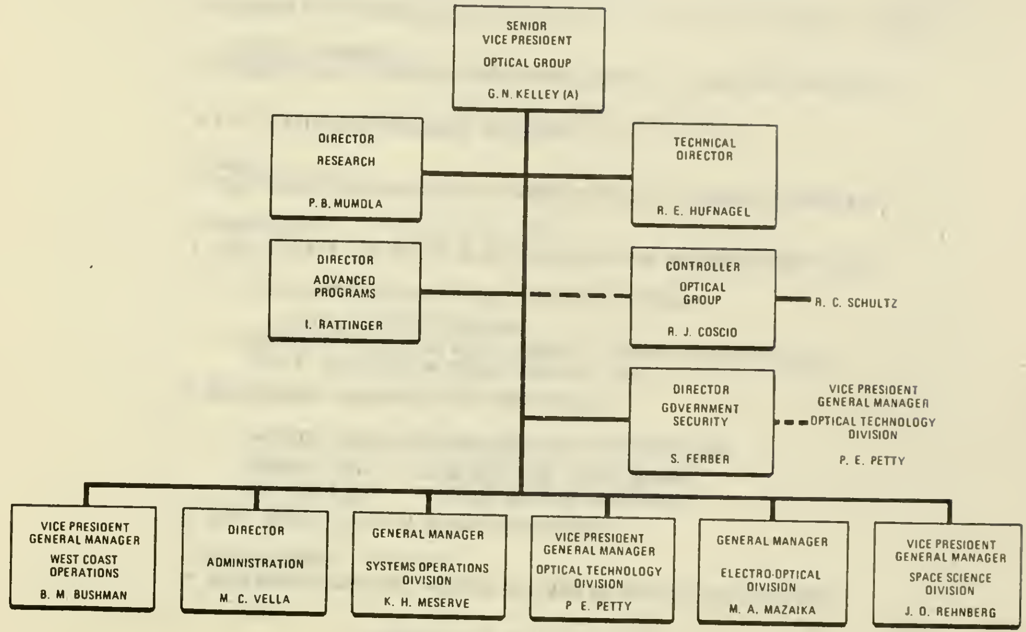


Figure 35

PERKIN-ELMER

OPTICAL GROUP – SPACE SCIENCE DIVISION

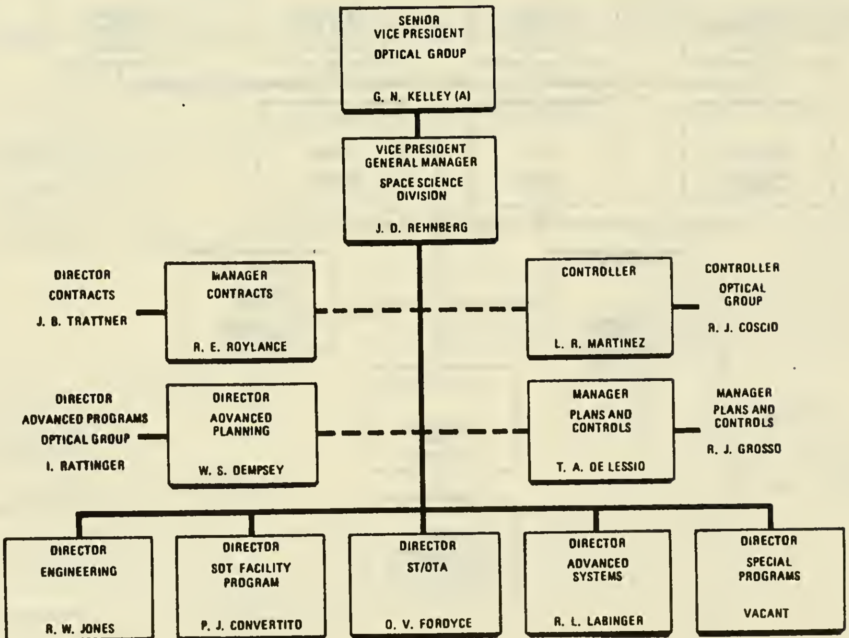


Figure 36

PERKIN-ELMER

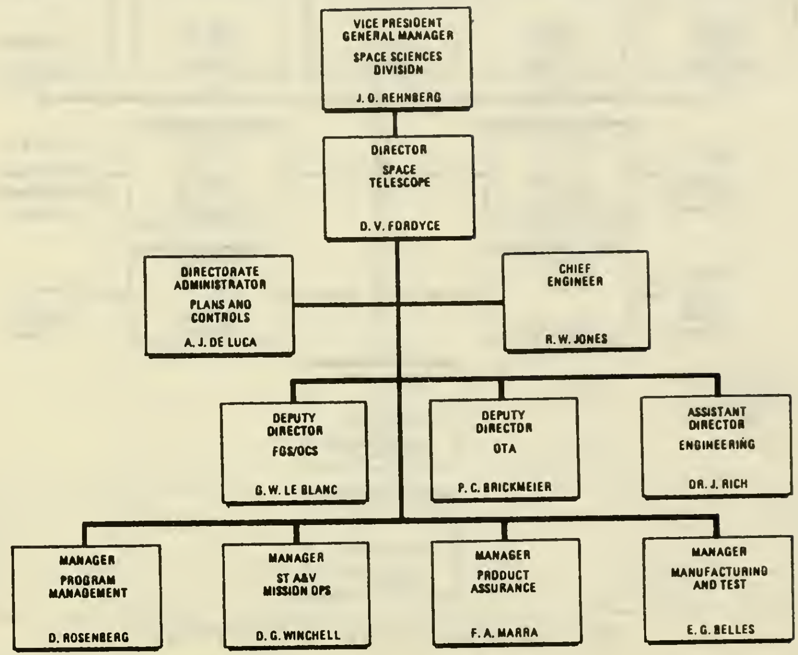


Figure 37

PERKIN-ELMER

OTA SUMMARY SCHEDULE

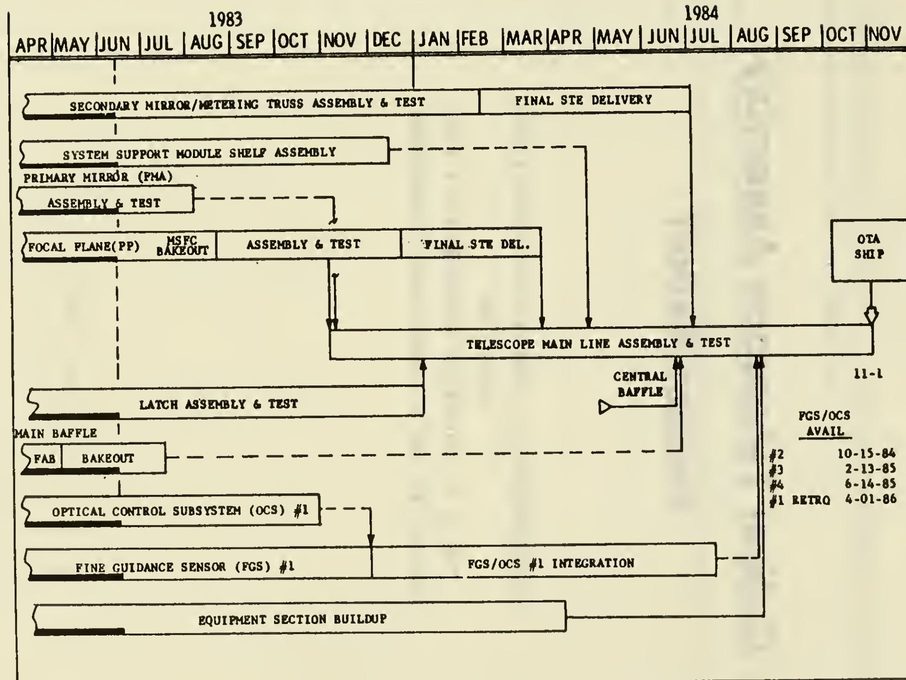


Figure 38

PR-825

Optical Telescope Assembly Project Report

IN RESPONSE TO ADDITIONAL QUESTIONS
POSED BY
THE U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY

July 1983

Contract NAS 8-32700

PERKIN-ELMER
OPTICAL GROUP

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama
35812

ST 2343-83

PR-825

Question 1:

Mr. Kelley, within the Optical Group what is the percentage of the group's total effort which is being devoted to the Space Telescope activities?

Response:

The Space Telescope Program currently accounts for 35 to 40 percent of the Optical Group's total orders. In prior years, this program accounted for 25 to 30 percent of the Group's total effort.

Question 2:

Mr. Kelley, how would you characterize the work performed within the Optical Group -- is it mostly government or commercial? Is it mostly research and development or production?

Response:

Work currently performed within Optical Group is nearly all government-sponsored and largely research and development.

Question 3:

(a) Mr. Kelley, within the Optical Group what is the percentage of fixed price effort compared to cost plus contract effort?

(b) Are you aware of any mischarging of labor or materials from your fixed price contracts to your cost plus contracts?

Response:

(a) The Optical Group's business is currently 78 percent cost-type contracts. The Danbury, Connecticut facility where the Space Telescope Program is being performed has 95 percent cost-type business.

(b) No!

Question 4:

Mr. Rehnberg, how does the level of complexity and technical challenge of the Space Telescope Optical Telescope Assembly and Fine Guidance Sensor compare with other development undertaken by Perkin-Elmer?

Response:

The level of complexity and technical challenge inherent in the OTA - while a logical extension of Perkin-Elmer's earlier development efforts - represents a significant advance from the previously established state of the art in many fields.

In the past, we have produced 32 and 36 inch diameter, high quality ($\lambda/25$) mirrors for OAO-Copernicus and Stratoscope II, as well as many 12-to-18-inch-diameter, super high quality ($\lambda/100$) mirrors for ground-based use. Before the current development contract and as part of the technology demonstration efforts, Perkin-Elmer successfully polished a 60-inch mirror to a smoothness of $\lambda/65$. It had the flexibility of a 3-meter mirror and was the highest quality, large mirror yet fabricated. Still, no one had polished a 94-inch diameter, lightweight mirror to super high quality for applications in space.

Perkin-Elmer has extensive experience in high-reflectivity mirror coatings in the ultraviolet. However, when the program began, the coating chamber and the technology to coat the mirror to the required level of uniformity did not exist. Perkin-Elmer set about creating both the chamber and the technology.

Similar development was required in

- o Structural Stability Analysis
- o Fine Guidance Sensor Technology
- o Spacecraft Temperature Control
- o Graphite Fiber Reinforced Epoxy Technology
- o Optical Metrology Technology.

In each of these areas, Perkin-Elmer had directly related experience that had to be applied to the extension of the current state of the art.

Question 5:

Mr. Rehnberg, with regard to the effort associated with coating the optic, how did the actual costs and time required compare to the original projections?

Response:

See the insert provided for line 1802 on page 77 of the testimony transcript.

PR-825

Question 6:

(a) Mr. Rehnberg, could you elaborate on the problems incurred with the latch mechanism development?

(b) Why did you switch to a tungsten carbide coating?

(c) Why was tungsten carbide not considered in the first place?

Response:

The following references answer all parts of this question: lines 1815 through 1833 on pages 78 and 79, and the insert provided for line 1841 on page 79 of the testimony transcript.

Question 7:

What was the cost growth and schedule delay associated with the redesign of the focal plane flexure foot?

Response:

Please see the testimony inserted at line 1850 on page 80 of the transcript.

PR-825

Question 8:

Mr. Rehnberg, in your testimony you state that in the ultraviolet regions of the spectrum the primary mirror is marginally acceptable. Could you elaborate on what you mean by marginally acceptable?

Response:

I described the Primary Mirror as "marginally acceptable" in the ultraviolet because of the particulate contamination known to be on the mirror's surface.

The deleterious effects of dust particles are more severe at short wavelengths (ultraviolet) than at longer wavelengths (visible and infrared). Analyses have shown that, when the faintest stellar objects are viewed in the presence of very bright objects, the ultraviolet light scattered from dust particles will approximately equal the dark sky in the background, thus just beginning to compromise the quality of the image.

The mirror's reflectivity is essentially unchanged; it is the light scattered by the dust particles to form a higher background intensity that causes the problem.

In the spectrum's visible and infrared regions, the effect of dust is much less noticeable.

Question 9:

(a) How will you protect the mirror from contamination during the three years remaining before launch?

(b) Have the contamination problems associated with maintenance and refurbishment activities been carefully evaluated?

(c) How will you protect the mirror during retrieval and landing operations of the Space Shuttle?

Response:

(a) Perkin-Elmer plans to clean the mirror during the summer of 1984. Cleaning will remove most of the dust particles now on the mirror - but not all of them. Very soon after cleaning, a new primary mirror cover could be installed to seal the mirror's surface inside a closed vacuum. As conceived, this cover would be flexible to allow for atmospheric pressure changes, with the air inside the cover remaining at Class 10,000.

Perkin-Elmer envisions this cover's being removed from the fully assembled Space Telescope shortly before launch. It could be removed earlier, but once removed, it could not be re-installed. We recommend that this new cover, if accepted by NASA, remain in place at least through the ST's Acoustic Test at LMSC and preferably through delivery to KSC for launch preparations.

(b) Mission planning for Space Telescope's maintenance and refurbishment is not now included in Perkin-Elmer's OTA Contract, and thus Perkin-Elmer has not carefully evaluated these activities with respect to any potential contamination problems. Maintenance and refurbishment are being studied by LMSC under contract to MSFC.

(c) The Primary Mirror will be protected during retrieval and landing operations by the STS's bleed-in filter systems and by the ST's closed aperture door. It is likely that re-entry and landing will contaminate the primary and secondary mirrors with a dust layer that will require some level of disassembly and cleaning.

Question 10:

(a) Mr. Rehnberg, if molecular contamination were discovered, how would you remove it?

(b) Are the procedures for the molecular cleaning process already developed and understood?

Response:

(a&b) We have empirical evidence that there is no molecular contamination from checking our witness samples. However, should molecular contamination occur, the amount would have to be evaluated, and, if it's excessive, cleaning would be necessary. No procedures are ready for cleaning molecular contamination from the OTA's mirror surfaces. Such procedures would have to be developed from laboratory procedures. A wash may be used; however, this could degrade the surface, possibly requiring that the mirrors be disassembled and recoated. This would have a severe effect on the program.

Question 11:

(a) With regard to the Koesters prism needed for the Fine Guidance Sensor, could you characterize the fabrication and assembly difficulties?

(b) Is this problem primarily one of quality control?

Response:

(a) The fabrication of the Koesters prism is characterized by the difficulties of finishing the surfaces of two pieces of glass to a very small difference ($\lambda/15$) in optical path. The fabrication process requires very precise surfaces and very precise and uniform coatings applied to those surfaces. The assembly is characterized by the need to achieve optical contact between the two halves of the prism and to mount the unit in a way that leaves no stresses in the glass.

(b) The fabrication difficulties may be seen, in part, as a quality control problem because the quality control techniques used originally were not so sensitive and quantitative as they needed to be. New, more precise inspection techniques, accompanied by new supplemental specifications, are being applied and will improve the quality control to the level required.

Question 12:

Perkin-Elmer has been criticized for deficiencies in detailed work planning and scheduling. What type of work planning and scheduling system do you use?

Response:

The system is a PERT (Performance Evaluation Review Technique) network with associated man-loading for controlling schedule and labor cost.

Further elaboration can be found in the testimony transcript starting at line 2248 on page 97.

PR-825

Question 13:

Mr. Rehnberg, in your testimony, you note that the number of changes in the OTA program have been significantly higher than expected. Could you elaborate on this? Why so many changes?

Response:

Please see the response provided as an insert at line 2031 on page 88 of the transcript.

PR-825

Question 14:

In your testimony, Mr. Rehnberg, you state that OTA interfaces, particularly as influenced by the Shuttle, resulted in significant schedule and cost impacts.

(a) Could you be more specific with regard to these interface changes?

(b) What is the total cost and schedule impact associated with these interface changes?

Response:

Both parts of this question are answered in the transcript beginning at line 2036 on page 89 and in the insert provided for line 2052 on the same page.

Question 15:

Additional schedule and costs have been added to perform thermal vacuum bakeouts.

(a) Do you agree that these bakeouts are needed?

(b) What is the additional cost and schedule delay associated with this activity?

Response:

(a) Perkin-Elmer agrees that additional bakeouts are needed to reduce any possible risk of hydrocarbon contamination on optical surfaces. The program has already paid the premium to ensure that the hardware is kept uncontaminated, and there is no evidence of contamination on the principal structures. The consequences of contamination are severe, and all actions to reduce that risk should be taken.

(b) The initial estimate for baking out the Focal Plane Structure included an approximate delay of two months in the delivery of the OTA. Subsequently, restructuring of the program and additional bakeouts of the Fine Guidance System and other parts have reduced this estimate. As a result of restructuring the program to include this additional testing of the FGS, the cost resulting from the bakeouts is expected to be approximately $1 million with shorter delays than originally predicted.

Question 16:

(a) Is it desirable to be able to reprogram the Fine Guidance Sensors on-orbit?

(b) Will this capability be available?

Response:

(a) In a strictly technical sense, it is desirable to be able to reprogram the Fine Guidance Sensors on orbit. Such capability would provide the ultimate flexibility in meeting off-nominal and unexpected conditions.

(b) The Fine Guidance Sensors are not fully reprogrammable in that the electronics do not contain Random Access Memories (RAMs). Instead, the Fine Guidance Sensors employ Programmable Read-Only Memories (PROMs), which are pre-programmed on the ground, with performance adjustments made by changing and reloading some forty calculation constants from this group to the on-orbit spacecraft.

The decision to use PROMs instead of RAMs was made after such factors as complexity, power requirements, the RAM's susceptibility to radiation damage, and up-link requirements were considered. Given these factors and recognizing programmable flexibility elsewhere in the Space Telescope, we have been unable to establish any firm justification to incur the increase in cost and schedule associated with changing from PROMs to RAMs in the Fine Guidance Sensors.

Mr. Volkmer. We will now proceed with questioning under the 5-minute rule. The gentleman from California is recognized.

Mr. Brown. Mr. Rehnberg, could you describe this mirror for me a little bit more? I understand it weighs about a ton; is that right?

Mr. Rehnberg. Yes, sir. The mirror is 96 inches in diameter, approximately a foot thick. It is made of ultralow expansion fused silica. The manufacturer of the mirror is Corning Glass Works. The core of the mirror is made of a labyrinth of slots of ULE glass also, similar to an egg crate. We call them egg crate constructions.

It is formed in a slump form, one supplied to us by Corning. In that form the surfaces are rather rough. It weighs about 1,800 pounds. When we receive the mirror, then we begin the grinding and shaping of it to prepare it for the optical figuring necessary.

I would say if we had an equivalent piece of glass, if it were a solid, it would weigh at least three times that, so it would be about 6,000 pounds.

Mr. Brown. That is what I was interested in. Just juggling the numbers, it looked to me as though it ought to weigh a lot more than that. I am interested in how you achieved that.

Is it possible to achieve a lighter-weight mirror than that?

Mr. Rehnberg. Yes, sir, it is. One could achieve, perhaps, a few hundred pounds reduction consistent with conservative state of the art, and if one wanted to assume more risk, one could perhaps even reduce that more than that—risk being in terms of on-orbit performance. I would say that the form that we are using is a rather conservative form.

Mr. Brown. Is there another technology that can be used or segmented lightweight mirror that is computer controlled?

Mr. Rehnberg. Yes, sir.

Mr. Brown. Do they exist or are they just conceptual?

Mr. Rehnberg. They do exist. We had development programs for Marshall Space Flight Center as long ago as 15 years with that type of technology. There have not been any successful flights of forms of that type, to my knowledge.

I believe at the time of the program inception, which was 1973 to 1975, during the phase B, I think we had to with NASA select an approach which had minimum development risk.

As a matter of fact, at that point in time we did have an approach which, although it was a monolith, could have been lighter. Again, because of technical risk, no form like that had been carried forward. The decision was made to stick with the design that we currently have.

Mr. Brown. What is the meaning of molecular contamination?

Mr. Rehnberg. Let me just be brief on that, if I might. I am not an expert. I am not a spectroscopist.

Hydrocarbons are very deleterious to the ultraviolet reflectivity that is of so importance to the science community.

Most manufacturing operations have with them attendant atmospheres which have hydrocarbons in them. For example, when you machine a piece of aluminum or when you do most operations, they are wet machines with oil. If you do not remove all of that oil, all of that film, it could outgas in space and then redeposit on the surface of the mirror. That redeposition would absolutely annihilate the reflectivity of the primary.

What we have to assure ourselves, NASA, and the science community is that during all operations in preparation of the telescope that no hydrocarbon contaminants can be redeposited on the primary or the secondary optics.

Mr. Brown. On any of the components is what you are saying?

Mr. Rehnberg. On the reflective components.

Mr. Brown. You are not saying that it could outgas from other components other than——

Mr. Rehnberg. Well, it could outgas from one component and redeposit on the primary. Therefore, you have to control all the material going into the space telescope and assure yourself that there are no hydrocarbons present, and to take the precautions for that, as evidenced by Dr. Martin last year, we are now vacuum outgassing all major structures, all parts, and all cables in the program. That is a major activity ongoing right now.

At elevated temperatures in a hard vacuum or a space vacuum environment, all of these large structures are now being subjected to these kind of conditions, to remove any possible molecular contaminant that would be there.

Mr. Brown. What assurance do you have that this successfully removes it?

Mr. Rehnberg. What is done in this process, we have residual gas analyzers attendant to the chambers. We monitor the outgas constituents coming off. We operate the subsystem at a higher temperature than it will fly at. The vacuum levels or the simulated space levels are probably as good or harder than we would see in space. If we see nothing, then we know things are OK. If we do get something, then we would naturally keep it in the chamber until the residual levels were down to acceptable levels.

Mr. BROWN. You think that is not going to be a problem in terms of the actual performance when it gets into space.

Mr. REHNBERG. I do not believe so, if we take the right precautions.

Mr. BROWN. I have no further questions.

Mr. VOLKMER. Thank you.

The gentleman from Florida is recognized.

Mr. MACKAY. I have no questions.

Mr. VOLKMER. The gentleman from Virginia is recognized.

Mr. BATEMAN. Thank you, Mr. Chairman.

Mr. Rehnberg, there was a term on your chart that I am not sure that I fully understood what it means—"technical redirection." Can you explain what that means? It sounds like one of those things we invent here in Washington.

Mr. REHNBERG. Do you recall which chart it was, sir?

Mr. BATEMAN. No, I am afraid I do not. It was in the discussion as to factors which led to delays.

Mr. REHNBERG. Oh, I see it. Yes, sir. I have it right here. OK. I was just trying to get the context.

Program changes—a program of this nature, which is highly complex and sophisticated, is such that we start off with specifications from our customer, NASA, and we are designing and building to that specification. Now there could very well be changes in the program that we do not initiate. Let's say one of the associates—let's say the Europeans need a different interface requirement for their science instrument. The way that would be manifest would be in the form of a technical direction to us from NASA. Then it would either be considered—either we could accept it and do it or there might be some costs associated with performing that activity.

Mr. BATEMAN. The reason I asked the question, what you just said sounds to me like the rather typical, normal change in specifications, change in plans, based upon a more full perception of need, function, or scientific innovation. Do they really mean the same thing? Is this just a change in the specifications based upon technical observations or experience gained during the——

Mr. REHNBERG. It could be a combination of both. As we get into the design of the activity, maybe mutually we find a better way of meeting that requirement. We could both change our requirements, and that is all part of the integration activity associated with a program of this type.

Mr. BATEMAN. Do you have any perception that the technical redirections have been excessive beyond what would normally be expected or desirable, or perhaps that you have had technical redirection which was doing horrendous things to time schedule but of marginal significance? Could you give me some qualitative appraisal as to——

Mr. REHNBERG. I think all of the technical direction or redirection we received was substantive and when necessary.

One of the problems that may have resulted is that in accommodating some of these redirections, as I mentioned during the briefing, staffing levels, of necessity, due to funding limitations that were established in prior years, may not have allowed us to fully evaluate all of these technical redirections.

Mr. BATEMAN. At the bottom of page 12 of your statement, you make reference to having to reduce manpower to conform with budget estimates. From what you have just said, was it part of that necessity that technical redirection was eating up manpower and budget beyond what as originally expected and, therefore, you were not able to employ additional people that you otherwise would have employed but for the technical redirection?

Mr. REHNBERG. That is part of the situation. In other words, we, in preparing for budget cycles, will establish what we think our funding needs will be 2 years in the future, anticipating again a success-oriented program, as was indicated earlier in the testimony. We then have, in a high-tech program such as this, technical problems that have to be resolved like the solution to the flexure foot problem. We then also have to accommodate changes which are directed upon us, because if we cannot accommodate them, we have other people waiting on us.

In a situation where we are underfunding constraints now because of the fact that we helped establish what the funding levels were, the ability to respond to these becomes very difficult without impacting some other part of the program.

Mr. BATEMAN. One other aspect of this—and I guess it is because the technology is substantially above my level, but the inflation factor that is discussed on page 13 of your statement—certainly inflation was much with us during the late 1970's, as is suggested, and into 1980. Starting at least January 1981, it has been a declining factor, probably more significantly declining than most people would have estimated 2 or 3 years before 1981. In view of a lesser inflation rate since 1981, are we going to have some positive cost implications for the remainder of the contract?

Mr. REHNBERG. I think our financial people inflation factor estimates are pretty much in line with what we were anticipating at that time. I think for about the last year we were using models within a few percentage points of what we are seeing and realizing right now.

The problems with inflation that we realized had to do with anticipated costs at the beginning of the program, attendant with what we were entering into during the late 1970's and early 1980's, and the cost of manpower that was estimated in 1977 versus what it was in 1982 and 1983.

Mr. BATEMAN. I can certainly understand that estimates in 1977 for the period there until late 1980 might have been under, but over a longer-term contract it would seem as though somehow or another there ought to be a little balancing of the scales on this inflation factor.

Mr. REHNBERG. Perhaps we can get you an answer for that, if that would be appropriate.

Mr. BATEMAN. That is fine.

Thank you, Mr. Chairman.

[The information follows:]

Our original projections were based on the rates of inflation in 1976 and 1977, approximately 5 to 6 percent per year. The following table shows the actual escalation of our labor costs from 1976 through 1982.

Average of labor escalation factors experienced

P-E fiscal year:	Percent escalation
1976	5.5
1977	5.8
1978	4.9
1979	8.3
1980	10.1
1981	8.7
1982	9.9

Our vendors were experiencing escalating labor costs similar to our own. On the basis of these trends, it appears unlikely that the inflation rates for the remainder of the OTA Program could return to our originally estimated levels.

Mr. VOLKMER. I have several questions.

Mr. Kelley, I appreciate your statement, the part of your statement where you say that the principal reason or cause of many of the problems has been our misjudgment of technical complexity of several of the tasks required. I would like to know, within the optical group, what is the percentage of the group's total efforts devoted now to the Space Telescope activity?

Mr. KELLEY. I would estimate that 50 to 60 percent of the total optical group effort is being dedicated to this program at this time. That has not been true, of course, for the entire program, but at this particular time and for the past 6 months it has been somewhere in the vicinity of 50 to 60 percent of the total effort.

Mr. VOLKMER. As against about May of 1982 when we had hearings on this, how much would you say it was at that time?

Mr. KELLEY. I would say 30 percent perhaps.

Mr. VOLKMER. The rest of the effort in the optical group, is that on a commercial or Government——

Mr. KELLEY. It is all on Government.

Mr. VOLKMER. The rest of it is all on Government?

Mr. KELLEY. Yes.

Mr. VOLKMER. What is the percentage of fixed price effort compared to cost-plus contract effort within the optical group?

Mr. KELLEY. I would guess we are above 90 percent cost plus.

Mr. VOLKMER. What is the fixed price on what type of——

Mr. KELLEY. Government contracts of tactical weapon systems.

Mr. VOLKMER. Are you aware of any mischarging of cost plus or fixed price to cost plus?

Mr. KELLEY. Absolutely not.

Mr. VOLKMER. I am not saying there was.

Mr. KELLEY. I understand.

Mr. VOLKMER. I am just asking the question.

Now, Mr. Rehnberg, in the part of your statement here on page 1, I think at least to me it says that, "The publicity that the space telescope program has received in recent months has raised the notion that the program is in grave technical difficulty, and as a result less science may be accomplished."

At least I have not heard that. I was wondering where you heard that.

Mr. REHNBERG. Mr. Chairman, from what I have read in the paper and things of that sort, statements to the effect that 30 percent of reflectivity had been lost on the mirror, things of that type.

Mr. VOLKMER. Which is not accurate?

Mr. Rehnberg. That is correct, sir.

Mr. Volkmer. For the record, one thing that is accurate is that last year, Mr. Rehnberg, in May 1982, when you testified before this subcommittee, you were positive that you were going to be able to meet the schedule at that time.

Mr. Rehnberg. That is correct, sir.

Mr. Volkmer. What made the difference between then and now?

Mr. Rehnberg. As we were entering into the beginning of Government fiscal year 1983, we were starting to receive all of the major subassemblies, the primary mirror, the secondary, a number of the items associated with large structures and a lot of the ground support equipment and special-test equipment that was necessary in order to support that integration effort wound up being deficient for the job at hand.

Mr. Volkmer. Whose responsibility was that?

Mr. Rehnberg. That was our responsibility.

Mr. Volkmer. In other words, you did not have the necessary test equipment, adequate test equipment——

Mr. Rehnberg. To the precision that we determined at that time that we needed, so we had to modify some, develop some new ones, and even other ones that were not anticipated at the time. This had the resulting effect on schedule.

Mr. Volkmer. Up to, say, last year at this time, what type of working relationship did you have with the people at Marshall?

Mr. Rehnberg. I think the working relationship was an acceptably good one. I think we both have always respected each other technically. I think the communications were acceptable.

Mr. Volkmer. Was there any recommendation made by the people at Marshall concerning the testing equipment or what you may need?

Mr. Rehnberg. I do not believe they understood or expected the difficulties that we found ourselves in.

Mr. Volkmer. Was part of the problem that you had due to the fact that this was a success-oriented project?

Mr. Rehnberg. I think that is a big factor there. A lot of the test equipment that we had was developed very early in the program to support an integration effort that had been planned at Goddard Space Flight Center for that program. We had always assumed that that equipment would be adequate and we did not have to worry about it.

What happened, as we started getting into the integration phase, we determined that the adequacies of those items were very inadequate. We had to put substantial engineering resources to modify them and to upgrade them and to bring them in line consistent with the system requirements of that point in time.

Mr. Volkmer. When did you bring to the attention of NASA the problems that you have foreseen?

Mr. Rehnberg. Immediately upon our discovering this. I would say August, September.

Mr. Fordyce. It started in August and our actual resolution of the problem, to the extent at which we see it today, was during the holidays between Christmas and New Year's when we finally went through each individual piece of equipment identified in our level 4 schedules and our plans at that time.

Mr. VOLKMER. Was there any fault in the people within the management of the program at Perkin-Elmer as far as being able to determine what should have been there as against what was there?

Mr. REHNBERG. I think we have to take the rap for that. Yes, I think we should have been more perceptive to the advance-looking requirements of the program. However, again because of the manpower constraints on the program, most of the available manpower was devoted to meeting the program requirements at hand at the present time as well as meeting problems as they arose; for example, the correction to the flexure problem on the flight focal plane deck. The limitation of manpower really did not allow us flexibility to project ahead and look ahead and anticipate problems downstream.

I believe now we are better structured with sufficient manpower to be able to do that.

Mr. VOLKMER. Who imposed the limitation on manpower?

Mr. REHNBERG. I think we jointly did it—ourselves and NASA—by establishing budgets to use prior to that particular year.

Mr. VOLKMER. You did not anticipate the need for the additional manpower?

Mr. REHNBERG. Yes, sir.

Mr. VOLKMER. Hopefully, you think we have learned something positive from this experience?

Mr. REHNBERG. I think the Hearth Committee recommendations ought to be adhered by all programs.

Mr. VOLKMER. Now, Mr. Rehnberg, with regard to the effort associated with coating the optic primary mirror, how did the actual cost and time required compare to the original projections?

Mr. REHNBERG. Mr. Chairman, I do not have the cost numbers on that. We will get them for the record.

[The information follows:]

In the contract baseline established in 1980, the plan for all activities relating to coating the Primary Mirror showed completion in July 1981 at a total cost of about $3.9 million. The Primary Mirror was coated in December 1981 at a cost of about $5.6 million.

Mr. REHNBERG. As far as the time associated with that, we were, I believe, 6 months later than we had hoped to be. We had hoped to complete that operation in May 1981. The completion was December 1, 1981.

Mr. VOLKMER. And there would be, of course, additional costs?

Mr. REHNBERG. Yes, sir. I might add, also, that one of the major problems or difficulties there also was associated with the handling equipment.

Mr. VOLKMER. I would like for you to elaborate on the latch mechanism development. I understand you had to move from one type of material to a different type?

Mr. FORDYCE. Latches, as has been brought up, have some very stringent requirements on them, both in requirements for alinement of the science instruments and the fine guidance——

Mr. VOLKMER. But we knew this right from the beginning?

Mr. FORDYCE. That is correct, sir.

I am getting to the problem here. We had additional problems, then, with a low thermal gradient requirement across the interface. The latch did meet those requirements, but very recently, about 3 months ago I believe, some testing was done at Marshall Space Flight Center and they saw that the coating on the ball of the latches you saw had started to erode off of the ball. It was galling actually. It looked like, then, if we had a lot of material transfer, you could in space get into problems by trying to install another instrument with a ball on it, and you would not have the clearance necessary because the material had transferred over. A tungsten carbide coating was successfully tested, and that problem now is solved.

Mr. VOLKMER. Why was the tungsten carbide not considered in the first place?

Mr. FORDYCE. I really cannot answer that. We will have to supply that answer.

Mr. VOLKMER. I would like to know. Was it even considered or, if it was considered, was it rejected or what?

[The information follows:]

The need to stabilize the alignment of Science Instruments and Fine Guidance Sensors dictated a design that would ensure low, post-launch residual torques at each latch fitting. Materials and coatings with low coefficients of friction were investigated. The selection of one aluminum-oxide-coated ball in contact with a titanium spherical seat was based on this requirement for low friction. Galling risks were considered low on the basis of published coating data; so tungsten carbide was not considered at that time. After dynamic testing revealed the presence of galling, other coatings of higher hardness were investigated for suitability. Tungsten carbide, which was not considered initially because of its higher coefficient of friction, was then selected on the basis of discussions with the supplier. Subsequent dynamic testing at MSFC has proven that the coating meets all requirements.

Mr. VOLKMER. Can you tell me, also—if not, supply it to me—on the cost growth and schedule delay with the redesign of the focal plane flexure foot. I would like to know that additional cost.

[The information follows:]

We estimate the cost growth and schedule delay associated with redesigning and fabricating the Focal Plane Structure's Feet to be $3 million and two months.

Mr. VOLKMER. Now, Mr. Rehnberg, I believe in your testimony—and I would like for you to explain this because to me it means something may be different than what it actually is, and I would like to have it for the record—in the upper regions of the spectrum you stated that the primary mirror is marginally acceptable. Explain to me what you mean by "marginally acceptable."

Mr. REHNBERG. All right. I was referring to the particulate contaminant that is on the mirror right now, not the contamination that could be due to molecular. We do not believe there is any molecular.

Our scientists have done some analyses to determine the faint object degradation effect of the telescope. By that, we mean, in other words, trying to observe a 27th magnitude star while a companion star of maybe 4th or 5th magnitude is nearby in the field of view. That brightest star would cause scattered light, which would make the observing of the faint start less obvious. This scattering function is a function of wavelength. With the modeling that our people came up with, if we did nothing with the scatter particulate matter on the mirror right now, we believe it would be acceptable for visual observations, but if one wanted to do very faint object viewing in the ultraviolet, it would be marginal.

We believe, however, that by removing the dust contaminants next summer, it will be more than acceptable.

Mr. Volkmer. Do you plan to just leave it in the cleanroom until you are ready to clean it off?

Mr. Fordyce. As you saw in one of the first viewgraphs that Mr. Rehnberg showed, the mirror is the basic startup of the assembly of the telescope. Therefore, some of the information that has been supplied that said it has been sitting in the cleanroom and not being used is incorrect that I have read, because the mirror is the basic startup, the mirror assembly and getting the hardware on the mirror and into the main ring. Therefore, it will have to be in the cleanroom continually through launch.

The mirror is not alone in a cleanroom, but it has a cover on it at all times that we do not have a requirement to access the surface of the mirror. At the times that the surface of the mirror require access—some of it is past now, but when we were installing what we called through the glass hardware which restrains the mirror to the primary ring and any time that we do any operation with the mirror itself, installing any hardware on the back of the mirror, we have to run interferometry tests on the mirror, and the cover is removed at that time. Otherwise, it is in the cleanroom and it is covered all the time.

Mr. Volkmer. Will that continue on down through the integration within the module?

Mr. Fordyce. Yes, it will. It will continue in various forms. As we build the telescope up, if you will, the cover locations are changed, the procedures are changed, on out through to integration at Lockheed, at which there are again covers that cover the cavity that the mirror is in.

Mr. Volkmer. Now, Mr. Rehnberg, if molecular contamination or carbons were discovered on the primary mirror—I guess the secondary mirror maybe as well, but it is not nearly as important, I guess—how would you clean it off? What would you do?

Mr. Rehnberg. It would be I think equally disastrous on the secondary, Mr. Chairman.

Mr. Volkmer. That is what I say, but how do you clean it off?

Mr. Rehnberg. I believe that we would be in deep trouble.

Mr. Volkmer. The only thing we can do, in other words, is make sure it does not occur?

Mr. Rehnberg. That is correct. I believe our specialist would recommend no agitative cleaning with solvents of that coating for fear you would damage the coating, not that you wouldn't try that—if you were going to strip the coatings and start all over again, I would presume before you did that you would try to at least clean it physically. I think we would all be in very deep trouble if we had a contamination problem.

Mr. Bateman. Would the chairman yield for a followup on that?

Mr. Volkmer. Yes.

Mr. Bateman. Has the secondary mirror been fabricated and delivered?

Mr. Rehnberg. The secondary mirror has been fabricated. It has been in a much more clean environment. It was in an encapsulated enclosure. It is integrated into its main cell. I showed you hardware pictures today. We do not think we have any—since the in-process work associated with it—we can protect the mirror better than we can the secondary. It is in acceptable condition. It is smaller, also.

Mr. BATEMAN. That is the reason for my asking the chairman if he would yield. If it has been made, if it has been delivered, you say if it is contaminated we have a real problem, I would rather you would have said, "Thank goodness, it is not contaminated because if it were, we would have a real problem."

Can you say that it is not——

Mr. REHNBERG. I will say it is not contaminated.

Mr. BATEMAN. I feel much better.

Mr. REHNBERG. All of the witness samples that we have had in proximity to the primary and secondary mirror are tested regularly. These were coated at the same time the primary and the secondary were coated. We routinely move them and measure their reflectivity at the Lyman Alpha line, and we have not seen any effect or change in the reflectivity since the mirror was coated 18 months ago.

Mr. FORDYCE. We might add, also, that the samples that we took on the mirror, we took a tape sample at the edge of the mirror, not in the reflective path of the mirror, and those particles were analyzed by spectrograph and there were no hydrocarbon particles in those samples.

Mr. BATEMAN. Pardon my interruption, Mr. Chairman.

Mr. VOLKMER. I would like to talk about one other area on page 11, on the fine guidance system and the interferometer problem. There I guess it is basically with the prisms; is that correct?

Mr. REHNBERG. Yes, Mr. Chairman.

Mr. VOLKMER. How would you characterize the problem with that? Is it in the fabrication of them, a defect or——

Mr. REHNBERG. The problem that we identified had to do with the manner in which they are finally tested. We do not see any problems in being able to manufacture those items, but the test method that our opticians use is a little more qualitative, and we have come up with a more precise way of finally testing them. In other words, one could get ambiguous data as acceptable data, as we know right now. This is why we had some that were acceptable and some that were marginally acceptable.

Mr. VOLKMER. In other words, it is not necessarily with the subcontractor, Harris or whoever is making——

Mr. REHNBERG. Oh, no. Excuse me, Mr. Chairman. Are you talking of the interferometer?

Mr. VOLKMER. Yes.

Mr. REHNBERG. Harris makes an electronic subsystem. They only make one of the subsystems as part of the fine guidance.

Mr. VOLKMER. Who does the prisms?

Mr. REHNBERG. Perkin-Elmer. We make the prisms.

Mr. VOLKMER. You make the prisms?

Mr. REHNBERG. Yes.

Mr. VOLKMER. It was not with the manufacture or making of the prisms. It was with the question of testing as far——

Mr. REHNBERG. The testing of the prism.

Mr. VOLKMER. That has been overcome?

Mr. REHNBERG. Yes, sir.

Mr. VOLKMER. Again, I notice in there you say that this form of sensor was built and demonstrated in the laboratory by Perkin-Elmer in 1976. Again, going to the type of program we are doing, did you anticipate after doing that that you would have any problems with the fine guidance system whatsoever?

Mr. REHNBERG. No, sir, we did not. We knew it would be a very challenging, difficult machine to construct and build and design and that we would have to be attendant to all of the structural and thermal and optical constraints but we did not see it as a major technological challenge, although a very difficult one.

Mr. VOLKMER. If I understood you correctly, I thought I heard you say something to the effect that some of the problems with the fine guidance system and completing was caused by some requirements or something made by Lockheed?

Mr. REHNBERG. Well, we are associates, Mr. Chairman, and we do share requirements. We work together. I would say that they have not caused any problems. We do work together as associates and have a very critical interface, as was described by Mr. Wright.

The evolution of the pointing control subsystem and fine guidance systems requires that our teams work very effectively together.

Mr. VOLKMER. Now in your testimony you say the number of changes in the optical telescope assembly program have been significantly higher than expected. Can you tell us what those changes were?

Mr. REHNBERG. I think we can supply them for the record. I do not have the exact numbers on hand.

Mr. VOLKMER. I would appreciate knowing that. I would also like to know who made the requirements for the changes, where those changes came about or how they came about.

Mr. REHNBERG. We will do that.

[The information follows:]

From the establishment of the October 1980 baseline through the presentation to the NASA Administrator on February 23, 1983, approximately 60 changes were directed by the contractor. They can be categorized as follows:

Additional hardware	16
Additional testing	16
Design improvements	14
Systems engineering	9
Others	5

These changes often evolved through the combined requirements of NASA, the associate contractors, the science community, and development difficulties. In most cases, no single source of a change can be identified.

Mr. VOLKMER. Also, I believe one of the things you said in the growth is that it is influenced by operations of the shuttle. I was wondering how that impacted on the optical telescope assembly.

Mr. REHNBERG. As I stated before, Mr. Chairman, the major impact had to do with the loads that you would receive for the vibration and static loads associated with the environment that the shuttle would provide to the telescope during launch and landing. It was not until well into the program that these kind of settled down. As they changed upward or downward, we had to modify and change the designs accordingly.

Mr. VOLKMER. Was there any large impact on the cost or delays because of that?

Mr. FORDYCE. I think we would have to supply that. There were obviously delays by use of manpower and what have you. We can supply you that data.

Mr. VOLKMER. I would like to have that information.

[The information follows:]

During the course of the OTA Program, several shuttle load cases were used to design and build the OTA. The specific contract changes resulting from the variance of shuttle load data were in the order of $2 million. The changing load requirements necessitated reanalysis or design and some retesting of hardware, disrupting the normal flow of the program plan. As a result, the additional effects on cost and schedule are difficult to quantify.

Mr. VOLKMER. As I understand, we have had additional schedule costs added to perform your thermal vacuum bakeout; is that correct?

Mr. FORDYCE. That is correct.

Mr. VOLKMER. Do you believe or agree that these bakeouts were necessary?

Mr. FORDYCE. Yes, I do. A lot of these bakeouts were in the program earlier, and some analysis had proven that they possibly could come out. I think it is much better that they be in for the risk of the program. If there are any molecular contaminants on some of these structures we are baking out, they could come off in space and get on possibly the mirror surfaces, but it does take time to take this equipment and ship it to the proper location and have it baked out and bring it back on line again. In that case, there is a cost and schedule problem. There is no risk associated with this bakeout, except for transportation.

Mr. VOLKMER. On page 12, Mr. Rehnberg, in your statement you state that, the way I read it, you have a combination of underestimating technical challenges and you have a cumulative effect on your funding shortages, resulting from the inability to predict in sufficient time to meet the budget cycle the cost of meeting these technical challenges.

Why did you underestimate the technical challenges? What caused that?

Mr. REHNBERG. Mr. Chairman, the only rational reason that I can bring to that is that this is the first time Perkin-Elmer, and perhaps the Nation, has been attacking a problem of this type. We went into the program probably a little more optimistic than we should have. There have been attendant challenges and difficulties that had to be met.

Mr. VOLKMER. Then you say, "resulted in elimination of development testing, cutbacks on critical support hardware, interruption in certain development efforts, and, in general, operational inefficiencies."

In other words, it had quite a cumulative effect, then?

Mr. REHNBERG. Yes, Mr. Chairman. The test equipment that was eliminated earlier, the test items early in the program, had the effect of not giving the visibility early in the development cycle on problems.

Mr. VOLKMER. Did you bring these things to the attention of the people at Marshall at the time that they were occurring?

Mr. REHNBERG. I think we were part of the problem. I think together we were overly optimistic on achieving a success-oriented program.

Mr. VOLKMER. I guess my final question would be, now that we are at this point and we have the present schedule in line and we have the present funding that we presently know, do you believe that you will be able to maintain the schedule that is now required with the funds that are presently there or are you going to need additional money?

Mr. FORDYCE. I would make two comments on that, Mr. Chairman. One of them is that there will be additional changes in scope on the program that are not reflected in probably some of the data that you have, which will be given to you, I am sure, as soon as available by NASA, which do reflect the increased costs of the bakeout and spares that have been added to the program. With those incorporated into the program, we believe we have a success-oriented program for November 1, 1984 delivery.

Mr. VOLKMER. There is no question, Mr. Kelley, that as I review the structure you have placed people in more direct control and have now more, I would say, review process very periodically than you previously had; is that correct?

Mr. KELLEY. Yes, that is correct.

Mr. VOLKMER. Do you find that this has been helpful in moving the program?

Mr. KELLEY. Yes, I do, Mr. Chairman, quite so.

Mr. VOLKMER. What about anticipating needs that were not anticipated before?

Mr. KELLEY. I think there is an opportunity now to bring those needs to the forefront earlier, quicker, and get the attention that is required to solve them.

Mr. VOLKMER. I have no further questions.

Does the gentleman from Virginia have any further questions?

Mr. BATEMAN. Yes, Mr. Chairman.

The clean room, how clean is the clean room? Is it the highest state of the art in clean rooms or is it moderately clean or——

Mr. REHNBERG. Well, the highest state of the art is probably laminer flow-down systems that are used in the semiconductor industry, which we also use ourselves in some of our commercial activities. The requirements for the program call for class 10,000 clean room, and that is what the clean room is. It is monitored daily. It is a class 10,000.

I think if we were to go to the highest possibly cleanliness necessary at the beginning of the program, it would have added significant cost to the program.

Mr. BATEMAN. As I understand it, in a clean room it did get exposed to some contaminants, which has been a problem and a cost to correct, or do I misunderstand the problem?

Mr. REHNBERG. In every clean room there is some degree of particulate matter that precipitates in time. As Mr. Fordyce indicated, as we were doing the work in process with the primary mirror, the mirror, of necessity, from time to time had to be uncovered in this clean room. It was exposed for days, and sometimes weeks, in a vacuum chamber where we had to interferometrically test it. Even though we were within the class 10,000 spec requirements, we were building up a degree of particulate on the mirror.

Mr. BATEMAN. Then it would appear that you needed a little technical redirection in terms of the 10,000 quantum that you have mentioned.

Mr. REHNBERG. Yes, sir.

Mr. BATEMAN. Is it still in 10,000 or do you have now technical redirection on the degree of cleanliness of the clean room?

Mr. FORDYCE. The clean room itself is still classified as a class 10,000 clean room. However, the assembling area for some period of time now has been protected by tents effectively within the clean room, and the measurements in those areas, I do not have that data with me but it is considerably better than class 10,000.

The problem with a large room better than class 10,000 is that it would be horrendously expensive to build. No matter what class you have, if I could take an opportunity, please, no matter whether it is a class 100,000 or 10,000 or on down, you still have particulate matter in the air. The room is just cleaner.

If you take a piece of glass and expose it in a room, depending on the class it is, the glass is still going to be contaminated over some period of time unless it is in a vacuum. Obviously better than 10,000 is better, but if you went to class, say, 3,000, that does not necessarily mean we would not still be in the same problem we are in now.

Mr. REHNBERG. There is one other point. On these coatings, they build up electrostatic charges, which also become attractive surfaces for these particles. That is a phenomena that I think also has added to the complexity.

Mr. BATEMAN. This may be totally meaningless, but somehow or another it made an impact on my mind. Disabuse me of this: Did I hear you make reference to you had clean rooms for commercial projects, materials, and so forth, that were cleaner than the clean room where this mirror is?

Mr. REHNBERG. Sir, in the semiconductor industry it is very common to build devices in class 100. We provide quite a bit of equipment to that industry, and the area that we build and assemble this equipment in is of that magnitude.

Mr. BATEMAN. What is bothering me is whether or not we are being penny wise and pound-foolish if we have had some problems with particulates on this mirror. It is a mirror that we are going to put out in space at enormous expense above and beyond the fabrication, polishing, and what have you of the mirror. Once it is out there, you cannot go out there with Windex and clean it. It just seems like it is such an overriding concern that you would want virtually the maximum that you could have.

Mr. REHNBERG. I agree with you, sir, but again I believe, as stated by Mr. Fordyce, even though you are in a class 100 rather than a class 10,000, there is still going to be contamination.

Mr. BATEMAN. The visual training that you showed us had the thing with a cover over it. If I took a cover and put it over this picture, it would be covered but the air surrounding it would be the same old dirty air as is in the rest of the room. How much of a function does that cover serve in protecting it?

Mr. FORDYCE. The various——

Mr. BATEMAN. You can tell I am not a scientist.

Mr. FORDYCE. There are various types of covers, sir, that have been employed. Some of the coverings that have been with the mirror prior to its final assembly will have been like a—if you will—pie plate turned upside down with very little space around for any air to come through. As we go into these assembly operations, the covers, as you saw, basically are plastic, and they are taped so that they are not just free-floating. They are taped around to keep the air transfer down up into the area where the surface is. Very shortly now we are going to be installing another type cover which has, again, a different type protection.

For some of the mirror movements, inasmuch as it is mounted in the main ring now, we have gone to the plastic-type coatings that you saw, which does not totally eliminate the possibility of air movement. It really cuts it down.

Mr. BATEMAN. Air movement is a critical part of the exposure, I take it, and what the cover does is reduce the effect of any movements in the air?

Mr. FORDYCE. As you saw the mirror, we did not just put the cover on the mirror. We cannot contact the surface.

Mr. BATEMAN. Yes, I understand that.

I take it the cover has no organic materials that could be at any at-risk to the device?

Mr. FORDYCE. That is correct.

Mr. BATEMAN. Thank you, Mr. Chairman.

Mr. VOLKMER. Going back to newspaper reports and things that I have heard, there has been one thing within Perkin-Elmer that seems to be at least stated by some, that deficiencies in detail work planning and scheduling—I would like to know what kind of work planning and scheduling system is presently used.

Mr. FORDYCE. We have over the last 6 months generated not a new system, but we have brought back some of the old systems and intensified the systems of work planning. Some of our problems have been recent and have been correctly reported. We did not have schedules on the floor at the level 4 level, which reflected a delivery date. We said at one time we thought we could deliver June 15. We are on a November date. It has taken us a while to get in the bottom schedules on the floor, if you will, like level 6, to allow the people to plan precisely to stay on schedule that the program is trying to run to.

However, that aside, we have manufacturing meetings every morning at 7:30 with the people from all the teams that are assigned to the subsystem. Their work packages are brought in and, for the most part now, we have both 72-hour and 11-day forecasts. We do keep track of every item that is not achieved or everything that cannot be started that is requested by these team members. We do that on a computer, and we have used that data to enhance our forward-looking as far as what has been holding us up, whether it has been drawings, parts delivery, lack of a technician, or whatever it has been, so that we can improve that operation.

We have, then, a meeting in the afternoon, and then I have a weekly scheduled meeting myself with the team members, so that I can also hear what their problems are at a different level and can get them transferred into me. Those are scheduled-type meetings.

Mr. VOLKMER. The last question goes back to one I asked before. I just want to make sure the record is clear on it and that I am clear in my own mind. It goes back to the question of funding and restraints because of lack of full-funding requirements.

In any of the fiscal years after you started on this project or at any time was the amount that you thought was necessary reduced by NASA?

Mr. REHNBERG. Mr. Chairman, no, it was not.

Mr. VOLKMER. Thank you very much. We appreciate your coming.

I just want to say that I think we can all be proud of the work you have done on the mirror, et cetera. It is just a question, like you say, of not anticipating things that should have been anticipated.

Thank you.

Now we have the Hon. James Beggs, Administrator of the National Aeronautics and Space Administration.

Your statement will be made a part of the record, and you may review it or summarize, however you so desire.

STATEMENT OF HON. JAMES BEGGS, ADMINISTRATOR, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, ACCOMPANIED BY SAMUEL W. KELLER, DEPUTY ASSOCIATE ADMINISTRATOR

Mr. BEGGS. Thank you, Mr. Chairman. I have a summary that I would like to read.

Mr. Chairman, members of the subcommittee, I consider it a privilege to have the opportunity to appear before this committee and to discuss with you the space telescope situation. I appreciate the forebearance of both the committee and its staff while we have been working to correct the serious space telescope problems that I described to the committee during my testimony on February 3, 1983. After the space shuttle, this program is clearly the top priority program in NASA and it is one to which I am committed to achieving a successful conclusion.

As I previously reported to the committee, we have had problems in the development of this unique instrument and are taking significant steps to rebaseline the program in order to make a firm commitment both to the administration and the Congress on a revised schedule and total cost. At the same time, we have been reviewing our management practices and technical approaches, both within the agency and at the associate contractors, to determine what caused these problems and to learn how to prevent further occurrences on either the space telescope or other NASA programs.

In reviewing the present situation, there are numerous contributing factors to the problem recently confronting us. While no single event caused our present difficulties, the cumulative effect was such that we found ourselves faced by a difficult situation which, in retrospect, should have been recognized earlier. I believe both the agency and its contractors seriously underestimated the technical difficulties which had to be overcome in order to successfully complete this program. The space telescope may well be the most challenging spacecraft ever developed by NASA. However, advanced research and high risk technical undertakings are the essence of NASA's mission, and we must continually strive to improve our ability to take on ever more difficult assignments.

In addition to the technical challenge presented by the telescope itself, the agency selected a management structure which included two different field centers and a number of associate contractors, with Marshall Space Flight Center assuming the role of "prime contractor." We now recognize that we did not provide sufficient manpower to properly monitor the project.

Since I testified before this committee in early February, I have personally visited Perkin-Elmer, Lockheed, and the Harris Corp., to ascertain the progress they are making in the telescope program. At the same time, the Office of Space Science and Applications has conducted a detailed review of all aspects of the space telescope program which resulted in a briefing to me that highlighted various problems and recommended improvements to overcome these difficulties. We have reorganized the NASA headquarters program staff to enable us to more effectively control the progress of the space telescope and to revalidate the requirements imposed on the total system. Significant changes have also been made in the project management staff at both the Marshall and Goddard Space Flight Centers. With our encouragement, the Perkin-Elmer Corp. has continued to improve their management organization, and we have added a capability at Lockheed for program-wide systems engineering.

In parallel with these actions, we have reassessed the technical difficulties inherent in this program and are in the process of realining our schedule and cost estimates. As a result of this latter activity, a number of necessary steps are being taken which include the identification of a significant amount of test equipment and handling fixtures which had been omitted from earlier Perkin-Elmer planning estimates. We have also identified additional spares which are required to insure reasonable progression through the assembly and verification phase of the program.

In the area of schedules, our review indicated that unwarranted optimism had been permitted in an effort to maintain the 1985 launch schedule. By rescheduling the remaining activities to provide reasonable contingency periods, we are able to provide more efficient scheduling and provide for the inevitable problems that occur in a program of this nature. The recognition of a need for additional spares and test equipment, as well as the additional schedule time necessary to integrate and check out an instrument of the complexity of the space telescope, will result in new cost estimates which will be reflected in our revised program.

We have not compromised, nor do we plan to compromise, any of the performance requirements initially established for the space telescope. This is not to suggest that there are not serious technical questions to be resolved or that the accomplishments of these objectives will be easy. Our review to date, however, indicates that we are making steady progress toward the completion of an outstanding orbital facility with long-term science benefits. Specifically, we have completed the large 2.4-meter primary mirror; and, it performs better than specification. The primary mirror has been mounted in the main ring, and this has been done without inducing any distortion into the mirror. Preliminary assembly of a fine guidance sensor has been accomplished, and we are encouraged that progress is being made toward the ultimate solution of the fine guidance system problems. The activities at Lockheed are proceeding with the basic elements of the support system module in the integration phase.

The five scientific instruments are well on their way to completion and have only the normal final engineering problems expected in a difficult development program.

The Space Telescope Science Institute has been established on the Johns Hopkins University campus in a new building which was dedicated yesterday.

One of the major challenges faced by the program at this time is completion of the engineering model fine guidance sensor and a demonstration that, in fact, it can track a 14.5 visual magnitude star and can maintain lock on such a star for a 24-hour period. Although we have not demonstrated the ability to accomplish this objective so far, we are encouraged by preliminary tests which show that the Koesters prism interferometers will work as designed and that light rays can be accurately transmitted through the system.

I am sure you have heard of the question of primary mirror contamination which is a problem of some concern. Preliminary analysis indicates that current particle distribution is acceptable in the visible range and marginally acceptable in the ultraviolet range. There exist cleaning techniques which will permit us to remove particulate surface contamination, but, because of the critical nature of this process, I have directed the project office to review their analyses and proposed cleaning procedures with me before any action is initiated.

In reviewing your technical challenges, I must also mention the unknown problems that may occur during the final assembly and verification process. This is a very complex instrument, and it would be unrealistic not to expect that problems will be encountered during that activity. We believe that, by improving our spares capability and by providing prudent contingency time in the schedules, we will be able to overcome these difficulties as they arise. Finally, there is the problem of verifying the optical integrity of the completed instrument prior to launch. To the extent our analyses and tests do not compensate for all assembly errors, we have provided a capability to alter the figure of the mirror on orbit and to adjust the position of the secondary mirror.

In terms of schedule, we have now developed both overall and major subsystem schedules which provide for delivery of the optical telescope assembly and two of the fine guidance sensors to Lockheed by November 15, 1984. This will support a launch of the telescope in June 1986. Recognizing the challenges still present in this program, the agency is prepared to make a commitment for a launch during the last half of calendar year 1986.

We have requested an increase in our fiscal year 1983 obligational authority of $45 million, which would bring the fiscal year 1983 plan for the development line to $182.5 million. For fiscal year 1984, we estimate the requirement of approximately $195 million, which is $75 million more than the January budget submission. While these represent significant amounts, I believe they are realistic and they will support the schedule I have outlined.

A completion of the scheduling activities will be necessary for us to arrive at a final runout cost, but I expect it will be in the $1.1 to $1.2 million range and will be a function of the launch date that we are able to achieve. As soon as these numbers become firm later this summer, I will certainly advise the committee of our conclusions.

In summary, it is not pleasant to review before this committee problems of the nature we are addressing today. However, I believe that our analysis has been open and thorough, that we have identified those problems remaining in the space telescope, and that we have made reasonable provision for their solution. There are certainly major risks remaining in the completion of this very difficult and challenging program. However, I believe that we have made a reasonable tradeoff between necessary reserves and fiscal restraint. We are developing a revised program which we believe can be completed on the new schedule and within the dollar range I have outlined. At the same time, I believe we have objectively reviewed the management practices of NASA headquarters, the involved field centers, and our principal contractors; and, we have taken steps to make those changes required to successfully accomplish the program. Perhaps more importantly, I believe we have learned lessons from the problems encountered in the space telescope which will serve us well on future programs of a similar challenging nature. The scientific benefits to be derived from the operation of the space telescope will warrant the attention we have been required to devote to it, the continued support of the administration, and particularly the guidance and the support that we have been provided by this and other committees of the Congress.

Mr. Chairman, that concludes my statement.

[The prepared statement, plus answers to questions asked of Mr. Beggs follow:]

Statement of

James M. Beggs
Administrator

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Before The

Subcommittee on Space Science and Applications
Committee on Science and Technology
House of Representatives

Mr. Chairman and Members of the Subcommittee:

I consider it a privilege to have the opportunity to appear before this Committee and to discuss with you the Space Telescope situation. I appreciate the forebearance of both the Committee and its staff while we have been working to correct the serious Space Telescope problems that I described to the Committee during my testimony on February 3, 1983.

The Space Telescope is the centerpiece of the NASA program in Space Science and Applications. I am convinced that this instrument will be the most important scientific instrument that has ever been flown and that its contributions to man's understanding of the universe will be as profound as anything since Galileo first observed the heavens through a telescope. The support of this Committee and the Congress as a whole, as well as this and previous Administrations, has been unfailing. The personal interest in the Space Telescope expressed by the Science Advisor to the President is clear evidence of the importance attached to its successful operation. After the Space Shuttle, this program is clearly the top priority program in NASA and is one to which I am committed to achieving a successful conclusion.

As I previously reported to the Committee, we have had problems in the development of this unique instrument and are taking significant steps to rebaseline the program in order to make a firm commitment both to the Administration and the Congress on a revised schedule and total cost. At the same time, we have been reviewing our management practices and technical approaches, both within the Agency and at the associate contractors, to determine what caused these problems and to learn how to prevent further occurrences on either the Space Telescope or other major NASA programs.

In the course of my testimony today, I believe it appropriate to discuss why the present problems were not identified sooner; what steps the Agency has taken to correct these problems; and what we now forecast in terms of telescope performance and further technical problems, schedules, and funding requirements.

Why Space Telescope Problems Were Not Identified More Quickly

In reviewing the present situation, there are numerous contributing factors to the problem recently confronting us. While no single event caused our present difficulties, the cumulative effect was such that we found ourselves faced by a difficult situation which, in retrospect, should have been recognized earlier. I believe both the Agency and its contractors seriously underestimated the technical difficulties which had to be overcome in order to successfully complete this program. The Space Telescope may well be the most challenging spacecraft ever developed by NASA. However, advanced research and high risk technical undertakings are the essence of NASA's mission; and we must continually strive to improve our ability to take on ever more difficult assignments.

At the time the program was initiated, there were many technical unknowns, such as the ability to fabricate the large 2.4 meter mirror with a surface accuracy necessary to achieve the Telescope's goals. The Fine Guidance Sensors were an equally difficult challenge. The problem of cleanliness, which is required in order to maintain an optical capability in the ultraviolet, was not thoroughly appreciated. This contamination problem has been made more difficult because of the need to fabricate many large structures from graphite epoxy which tends to readily absorb contaminate materials which later may be released in the reduced pressure in space and destroy the quality of the optical systems. The requirement to maintain very precise relationships between the focal plane instruments and the primary and secondary mirrors in a very harsh thermal environment has also presented a very difficult challenge. The scientific instruments compare in individual complexity to many spacecraft and have presented severe challenges in their own right. Since many of these types of unknowns had never been previously encountered, estimating the time and resources needed to overcome them became a difficult and uncertain task.

In addition to the technical challenge presented by the telescope itself, the Agency selected a management structure which included two different Field Centers and a number of associate contractors, with Marshall Space Flight Center assuming the role of "prime contractor." We now recognize that we did not provide sufficient manpower to properly monitor the project. We believe that additional in-house resources might have enabled us to pinpoint the problems at a much earlier date and, where necessary, provide government personnel to assist the contractors as we have done in the past on other programs.

Collectively, the problems I have described above have led to a situation where the Agency did not recognize the technical and management difficulties as early as is desirable. At the same time, I believe it fair to conclude that the technical challenges which have contributed most significantly to the present delays and cost increases were inherent in the program from the beginning but were not recognized at that time.

Steps NASA Has Taken to Understand and Solve the Space Telescope Problem

Since I testified before this Committee in early February, I have personally visited Perkin-Elmer, Lockheed, and the Harris Corporation to ascertain the progress they are making in the Telescope program and to understand any particular problems either within their own organization or which may be caused by actions on the government's part. At the same time, the Office of Space Science and Applications has conducted a detailed review of all aspects of the Space Telescope program which resulted in a briefing to me highlighting various problems and recommending improvements to overcome these difficulties. We have reorganized the NASA Headquarters program staff to enable us to more effectively control the progress of the Space Telescope and to revalidate the requirements imposed on the total system. Significant changes have also been made in the project management staffs at both the Marshall and Goddard Space Flight Centers. With our encouragement, the Perkin-Elmer Corporation has continued to improve their management organization, and we have added a capability at Lockheed for program-wide systems engineering.

In parallel with these actions, we have reassessed the technical difficulties inherent in this program and are in the process of realigning our schedule and cost estimates. As a result of this latter activity, a number of necessary steps are being taken which include the identification of a significant amount of test equipment and handling fixtures which had been omitted from earlier Perkin-Elmer planning estimates. We have also identified additional spares which are required to insure reasonable progression through the assembly and verification phase of the program. In prior years, many of the box level spares which would normally have been included in a program of this nature were eliminated as a cost-saving measure. Spares were provided only at the board or component level. As a result, if a particular subsystem were to fail during the integration and test phase, it would have been necessary to return the unit to the manufacturer for reinstallation of a new board or component. For certain key subassemblies, this could bring the entire process to a halt while the repair is accomplished. By providing spares at the subsystem or box level, we will be able to replace failed units immediately with a duplicate which will then permit a continuation of the main line activity. We believe these actions are necessary and prudent and will result in significant cost savings throughout the development program.

In the area of schedules, our review indicated that unwarranted optimism had been permitted in an effort to maintain the 1985 launch schedule. By rescheduling the remaining activities to provide reasonable contingency periods, we are able to provide more efficient scheduling and provide for the inevitable problems that occur in a program of this nature. The recognition of a need for additional spares and test equipment, as well as the additional schedule time necessary to integrate and check out an instrument of the complexity of the Space Telescope, will result in new cost estimates which will be reflected in our revised program.

Since the Directors of the Goddard Space Flight Center and the Marshall Space Flight Center have reviewed for you the changes made in their management structures and the contractors that they are responsible for, I will not repeat that information here. However, I should explain in some detail the changes that have been made in the NASA Headquarters organization. We have established a Space Telescope Development Division which is responsible for the development, launch, and initiation of on-orbit operations of the Space Telescope. This organization reports directly to the Deputy Associate Administrator for Space Science and Applications, who is devoting more than 50 percent of his time to this program. A dedicated Headquarters staff, both system management and engineering support, is being provided to accomplish the necessary functions of this office. Particularly, they will maintain a much more detailed technical overview of the elements of the program. They are establishing a cost and schedule analysis capability which will allow us to monitor the progress of several elements of the program much more effectively than we have in the past. We are in the process of revalidating the top level system performance requirements which were derived from the original recommendations of the Space Telescope Science Working Group to insure that the Telescope is being developed consistent with these requirements and, at the same time, does not unnecessarily exceed the capability. Lastly, we have established a consulting group composed of certain members of the Space Telescope Science Working Group to advise NASA on their perception of our progress in meeting the necessary programmatic requirements. This group will have access to all elements of the program for purposes of fact-finding and will provide an independent, science community view of the issues which may affect Space Telescope system performance. This is consistent with our efforts to involve the scientists more intensively in Space Telescope development. The Headquarters staff will provide key engineering support as may be required by this group.

Performance and Schedule Projections

We have not compromised, nor do we plan to compromise, any of the performance requirements initially established for the Space Telescope. This is not to suggest that there are not serious technical questions to be resolved or that the accomplishments of these objectives will be easy. Our review to date, however, indicates that we are making steady progress toward the completion of an outstanding orbital facility with long-term science benefits. Specifically, we have completed the large 2.4 meter primary mirror; and it performs better than specification. The primary mirror has been mounted in the main ring, and this has been done without inducing any distortion into the mirror. Preliminary assembly of a Fine Guidance Sensor has been accomplished, and we are encouraged that progress is being made toward the ultimate solution of the Fine Guidance System problems. We believe that our problems with the Fine Guidance Sensor electronics at the Harris Corporation are now under control and that delivery will be made in accordance with our required schedules. We have fabricated the large graphite epoxy metering truss assembly which maintains the relative position of the primary and secondary mirrors. The activities at Lockheed are proceeding with the basic elements of the support system module in the integration phase.

The five scientific instruments are well on their way to completion and have only the normal final engineering problems expected in a difficult development program.

The Space Telescope Science Institute has been established on the Johns Hopkins University campus in a new building which was dedicated yesterday. Institute personnel are proceeding with the development of the guide star selection system and the science data acquisition system. The European Space Agency portion of their staff is now building up, and we anticipate a smoothly functioning integrated operation under the direction of Dr. Riccardo Giacconi.

One of the major challenges faced by the program at this time is completion of the engineering model Fine Guidance Sensor and a demonstration that in fact it can track a 14.5 visual magnitude star and can maintain lock on such a star for a 24 hour period. Although we have not demonstrated the ability to accomplish this objective so far, we are encouraged by preliminary tests which show that the Koesters prism interferometers will work as designed and that light rays can be accurately transmitted through the system. We are faced with a rigorous program of preventing both particulate and molecular contamination from affecting the performance of the Telescope in the ultraviolet region of the spectrum. Among other actions, we have now included in our program the bakeout of those graphite epoxy structures which could otherwise contribute to possible molecular contamination.

I am sure you have heard of the question of primary mirror contamination which is a problem of some concern. Although the mirror is maintained in a clean room, no such facility is absolutely clean; and, during the storage period, some particulate contamination of the mirror has been observed. Perkin-Elmer has performed macrophotography of the mirror surface to characterize the particulates and has determined the nature of the contaminates by removing small samples from the edge of the mirror and analyzing them with x-ray emission spectroscopy. The particles are of types expected in a clean room assembly facility. Particles have the effect of scattering light and, thereby, affect the capability to observe faint objects in the presence of bright objects. Preliminary analysis indicates that current particle distribution is acceptable in the visible range and marginally acceptable in the ultraviolet range. Molecular contamination would be a different problem. The mirror history and examination of witness samples, however, do not give us any reason to suspect molecular contamination, but procedures will be developed to acquire direct evidence to confirm this. There exist cleaning techniques which will permit us to remove particulate surface contamination; but, because of the critical nature of this process, I have directed the project office to review their analyses and proposed cleaning procedures with me before any action is initiated.

In reviewing our technical challenges, I must also mention the unknown problems that may occur during the final assembly and verification process. This is a very complex instrument, and it would be unrealistic not to expect that problems will be encountered during that activity. We believe that, by improving our spares capability and by providing prudent contingency time in the schedules, we will be able to overcome these difficulties as they arise. Finally, there is the problem of verifying the optical integrity of the completed instrument prior to launch. Because the Telescope is designed to operate in the zero gravity of outer space, before launch the primary mirror is distorted by the earth's gravitational field such that it is not possible to perform normal optical tests while on the ground. We are investigating certain limited tests which can be performed during the assembly period that will increase our confidence that the instrument will perform on orbit as planned. To the extent our analytical analyses and tests do not compensate for all assembly errors, we have provided a capability to alter the figure of the mirror on orbit and to adjust the position of the secondary mirror.

In terms of schedule, we have now developed both overall and major subsystem schedules which provide for delivery of the Optical Telescope Assembly and two of the Fine Guidance Sensors to Lockheed on November 15, 1984. This will support a launch of the telescope in June of 1986. Recognizing the challenges still present in this program, the Agency is prepared to make a commitment for a launch during the last half of calendar year 1986. A final refinement of these schedules will depend on the development of detailed work package schedules which should be accomplished within the next several weeks. We believe that the detailed analysis of these work elements will support the schedules as I have stated above.

We have requested an increase in our FY 1983 obligational authority of $45M which would bring the FY 1983 plan for the development line to $182.5M. We now have before the Committee a request to reprogram $26M from Space Flight Operations from the previously planned deferral in FY 1983 and $19M from within Space Science and Applications to provide the required FY 1983 augmentation to the Space Telescope development program. The majority of the $19M will be made available from the Space Telescope operations and refurbishment funding and by stretching out the Solar Optical Telescope development activities at Perkin Elmer. I believe these adjustments can be accommodated without any major impact on other programs within the Office of Space Science and Applications.

For FY 1984, we estmate a requirement of approximately $195M, which is $75M more than the January budget submission. While these represent significant amounts, I believe they are realistic and they will support the schedule I have outlined. A completion of the scheduling activities will be necessary for us to arrive at a final runout cost, but I expect it will be in the $1.1 - 1.2 billion range and will be a function of the launch date we are able to achieve. As soon as these numbers become firm later this summer, I will certainly advise the Committee of our conclusions.

In summary, it is not pleasant to review before this Committee problems of the nature we are addressing today. However, I believe that our analysis has been open and thorough, that we have identified those problems remaining in the Space Telescope, and that we have made reasonable provision for their solution. There are certainly major risks remaining in the completion of this very difficult and challenging program. However, I believe that we have made reasonable trade-offs between necessary reserves and fiscal restraint. We are developing a revised program which we believe can be completed on schedule and within the dollar range I have outlined above. At the same time, I believe we have objectively reviewed the management practices of NASA Headquarters, the involved Field Centers, and our principal contractors; and we have taken steps to make those changes required to successfully accomplish the program. Perhaps more importantly, I believe we have learned lessons from the problems encountered in the Space Telescope which will serve us well on future programs of a similar challenging nature. The scientific benefits to be derived from the operation of the Space Telescope will warrant the attention we have been required to devote to it, the continued support of the Administration, and particularly the guidance and support that have been provided by this and other committees of the Congress.

Mr. Chairman, this concludes my prepared remarks. I will be pleased to respond to any questions you may have.

Written questions submitted by Chairman Volkmer during the June 16, 1983, hearing at which Mr. Beggs testified on the Space Telescope.

QUESTIONS A-1:

Mr. Beggs, we understand that initially there were limits on the manpower at Marshall that could be assigned to the Space Telescope.

a. What was this limit? Why was such a limit imposed?

b. When was this manpower ceiling raised?

c. Is Marshall under any limitations at the current time?

ANSWER A-1:

a. Initially, it was believed that only approximately 100 civil service personnel were needed on Space Telescope at the Marshall Space Flight Center to over-see the Space Telescope development activities. This belief was based on the perceived experience of the two associate contractors. However, as the design and development activities progressed, the need for additional manpower at MSFC was recognized.

b. The Marshall Space Telescope manpower level was increased in the latter part of 1978 and has grown to approximately 250 at the present time.

c. There are currently no limitations on MSFC manpower other than those dictated by prudent resource management.

QUESTION A-2:

a. Mr. Beggs, would you agree that the "systems engineering" effort has been understaffed in the past?

b. Why did NASA allow this situation to occur?

ANSWER A-2:

a. MSFC has overall responsibility for accomplishment of systems engineering--Lockheed is under contract to support MSFC in this activity. However, LMSC did not have explicit authority to penetrate across all program element interfaces, Science Investigators, etc., and hence, in some instances, systems engineering was inadequate, The most glaring example of inadequate systems engineering was in the area of Space Telescope assembly and verification. The project has now taken corrective measures to address Space Telescope integration and testing from a total systems viewpoint. Other areas are being reexamined to insure that all systems concerns are properly addressed.

b. Inadequacies in system engineering were not as clearly identified as they should have been because of what I now believe to have been inadequate penetration and oversight. These deficiencies are now being corrected.

QUESTION A-3:

a. Mr. Beggs, what has been the situation at Headquarters concerning the amount of manpower assigned to the Space Telescope program?

b. When did you first become aware that there were only two or three people at Headquarters involved in the Space Telescope program?

c. For comparison how many people in NASA Headquarters are assigned to Shuttle management?

ANSWER A-3:

a. and b. I do not think that the small number of people at Headquarters who were monitoring Space Telescope was the major contributor, but instead, because of the size and complexity of Space Telescope, the problem may have been the lack of a specific dedicated office for Space Telescope at Headquarters. We had previously relied on a group within an existing division which, I believe, had a definite effect on communication or lack of highlighting to top level management. We have corrected this situation by setting up a division in the Space Science and Applications Associate Administrator's office to manage the Space Telescope development activities.

c. A comparison of the number of Headquarters people on Space Telescope with the number of Headquarters people assigned to Shuttle management should be accompanied by noting that there are significant differences in the scope of effort and resources between the two programs and between the management and technical roles of the two groups. There are currently 56 civil service professionals at Headquarters assigned to Shuttle management, and there are 14 full-time professionals, including both civil service and contractor engineering support, assigned to Space Telescope development.

QUESTION A-4:

Mr. Beggs, we understand that there has been considerable turnover in the Headquarters program management responsibility.

a. Could you elaborate on the reasons for this turnover?

b. With this amount of turnover and only two or three people involved at Headquarters, how did Headquarters hope to maintain the necessary oversight and control of program progress?

c. With the split Center responsibilities and the procurement approach involving associate contractors, how did Headquarters hope to carry out its overall management responsibilities with only one or two people?

ANSWER A-4:

a. One of the difficulties of long duration programs is the turnover of people involved. The need for personal and professional career growth is one of the factors involved. For example, the first Headquarters Space Telescope Program Manager was appointed in May 1976 and remained for over three years until he was appointed Deputy Director of the Solar Terrestrial Division within the office of Space Sciences in November 1979. Career changes and advancements were also major motivations in the departure of other personnel.

b. In retrospect, it can be seen that the Space Telescope Development Program represented a large quantum increase in scope and difficulty over prior science projects, and normal communications which could ordinarily be relied upon to provide an adequate amount of data, were not adequate for the management, oversight, and penetration which the Space Telescope program required.

c. It became apparent as the Space Telescope program developed that NASA had not adequately assessed the enormous complexities in the Space Telescope program, particularly those deriving from multiple center involvement, two large associate contractors, and the absence of a single integrating contractor. It must be noted that the Headquarters approach in the past has been to act as much in a monitoring as in a management role for science and unmanned space programs. However, we are in the process of enhancing the management functions for Space Telescope at NASA Headquarters.

QUESTION A-5:

We understand that in the past, the integration and systems engineering contractor was prohibited from direct interaction with the principal investigators and the instrument contractors. Why was this barrier to communications imposed?

ANSWER A-5:

There was no prohibition of the systems engineering contractor interacting directly with the principal investigators and instrument contractors. During the early phase of Space Telescope development, the GSFC Space Telescope Project Office requested that all communication between the responsible parties for the scientific instruments and LMSC be conducted with a GSFC representative present. The intent of the policy was to maintain discipline in consideration of proposed changes or increases in scope o the work. However, it was determined that the above policy had to be changed to permit more direct exchange of information between the parties involved.

QUESTION A-6:

Mr. Beggs, would you agree that in the past the government imposed a number of artificial barriers which tended to inhibit good communications between all participants in this program.

ANSWER A-6:

There were no specific barriers built into the management system that were intended to inhibit communications. However, in retrospect, certain practices designed to protect component systems that had been developed for military purposes may have had a restraining effect on the free flow of information. Also, the existence of the very complex management structure selected may have inhibited communications somewhat. In addition, the initial understaffing at MSFC definitely had an effect on communications.

QUESTION A-7:

a. Mr. Beggs, what is your assessment of the manner in which NASA Headquarters has exercised overall management responsibility for the Space Telescope Program?

b. Have there been major disagreements over program direction or resource requirements between Headquarters and the Field Center?

c. How would you characterize the lines of communications between Marshall and Headquarters?

ANSWER A-7:

a. In retrospect, I have come to the conclusion that the organizational setting for the long and complex program may have had a definite effect on communication. We have now set up a separate division in the Space Science and Applications Associate Administrator's office to manage Space Telescope.

b. There have been no major disagreements over program direction or resource requirements between NASA Headquarters and MSFC.

c. The lines of communications between MSFC and Headquarters were adequate; however, as I stated above, I believe that the organizational arrangement and staffing levels of the Space Telescope project probably inhibited communication with top level management.

QUESTION A-8:

What are the major lessons learned from the Space Telescope development experience?

ANSWER A-8:

Probably the most important lesson that we have learned from Space Telescope is that the management structure that we set up for programs should be both adequately designed and staffed to stay on top of the program during the course of the research and development phase. In addition, we waited too long in coming down hard when we knew problems were developing in our contractors organizations.

QUESTION A-9:

Mr. Beggs, how would you characterize the working relationship between Marshall and Goddard?

ANSWER A-9:

Overall, the Space Telescope working relationship between MSFC and GSFC has been good, although at times it has been somewhat inhibited by institutional autonomies.

QUESTION A-10:

a. Mr. Beggs, would you comment on the award fee structure for both associate contractors?

b. Do you believe the contractors have earned the award fee which has been allowed.

c. Does the award fee structure need to be modified or changed in any way?

ANSWER A-10:

a. The award fee structures for Lockheed and Perkin-Elmer, the associate contractors, are basically the same. Each contractor is evaluated periodically, generally semi-annually, for attainment of contract performance during that specific award fee period. The award fee is based on performance under three major criteria: technical and schedule achievement, cost performance, and business management.

b. The contractors have earned the award fees granted to date, based on the predetermined criteria established for each of the specific award fee periods. The bulk of the award fee earned by Perkin-Elmer is for technical achievement, such as the primary mirror assembly, which exceeded specifications. Through November 30, 1982, Perkin-Elmer earned about 52 per cent of the available award fee and Lockheed earned about 91 percent of the available award fee on their contract.

c. The award fee structure for the Space Telescope is appropriate to the type of development effort involved, and provides equitable protection for both the Government and the contractor. Contractors are evaluated periodically, generally semi-annually, for attainment of contract commitments during that specific award fee period. The award fee is based on performance under three major criteria which are: technical and schedule achievement, cost performance and business management. Since returning to the Agency, I have grown increasingly concerned that we maintain a proper degree of diligence in the administration of cost-plus-award fee (CPAF) contractors. Because of this concern, I asked my Assistant Administrator for Procurement in December 1982 to set up a training program to reemphasize the objectives and rationale for CPAF contracting and to lay out some basic guidelines for proper CPAF administration. This training program is progressing extremely well, with training already completed at four field centers.

QUESTION A-11:

a. Mr. Beggs, as a result of a request from this Subcommittee, NASA conducted a study of its Program Management and Procurement Practices and Procedures during the previous Administration.

b. What steps have you taken to assure that the recommendations of this study were implemented?

c. Were the results of this study applied to the Space Telescope Program? If not, why not?

ANSWER A-11:

a and b. The procedures that will be used to implement this study have been documented in a NASA Handbook and distributed to all NASA program offices.

Some of the major elements in this handbook are: a high degree of project definition should exist before a program is presented as a new start; a formal definition and cost review should be conducted by a non-advocate team; commitment in writing by the center director and the project manager as to the resources required for project completion; the establishment of a contingency fund for each project, the magnitude of which will be a function of the assessed development risk; and an additional fund to be held at NASA Headquarters to protect against scope changes affecting the runout costs.

c. The Space Telescope program was well into the development state by the time the referenced study was complete. However, those parts of the study which could be applied to the Space Telescope have been or are being implemented, i.e., adequate visibility into contractor activities, insertion of adequate reserves, and reexamination of project management policies and intstructions.

QUESTION A-12:

Mr. Beggs, why did NASA pursue an approach using associate contractors as opposed to a prime contractor with subcontractors?

ANSWER A-12:

NASA was interested in obtaining the widest possible response from all qualified bidders for the Optical Telescope Assembly. NASA anticipated that some potential proposers may have had unique backgrounds and experience. The approach of using associate contractors appeared, under these circumstances, to be a good compromise.

QUESTION A-13:

How would you characterize contractor responsiveness to management changes suggested by NASA.

ANSWER A-13:

In recent months, both Perkin-Elmer and Lockheed have been very cooperative and receptive to suggestions from NASA regarding changes to this organization.

QUESTION A-14:

Could you elaborate on the organizational changes which have been made at Headquarters?

ANSWER A-14:

In order to gain more effective penetration of the

Space Telescope program, NASA Headquarters has created a separate line division devoted to the development of Space Telescope. The Director of this new Division is an experienced engineering manager. The Space Telescope Director also occupies a second position as Deputy Director for the Astrophysics Division to insure that the Space Telescope operations, science, and maintenance/refurbishment responsibilities are closely coordinated with Space Telescope development activities. Under the Director are three groups: the Program Resource Analysis Group which is manned by five people and is responsible for financial, manpower, and schedule analysis, as well as for implementation and maintenance of the automated management information system; the Engineering Support Group which is manned by seven people and is responsible for all engineering analyses, evaluations, and recommendations regarding technical development; and the Development and Integration Group which is manned by four people and is responsible for integration and test review and coordination, formulation of recommendations on program control and policy, and interagency activities.

QUESTION A-15:

a. Are you aware of any contractor mischarging which may have occurred?

b. Have you undertaken any investigations to look for contractor mischarging?

ANSWER A-15:

a. I am not aware of any intentional contractor mischarging. Recognizing that recording and accounting costs are not exact sciences, there have been occasional disagreements between government auditors and contractor accountants about accounting methodologies. I believe these disagreements have been equitable resolved.

b. We have not had reason to undertake any special investiagtions to look for contractor mischarging. However, NASA routinely utilizes the Defense Contract Audit Agency resident auditors in each contractor's plant. These auditors perform continuing audits of all costs incurred and perform periodic and random tests of contractor accounting practices and systems to validate the propriety of contractor charges.

QUESTION A-16:

Mr. Beggs, in your revised resources projections you are adding resources for additional systems engineering, additional spares, and other new effort. Additionally, the Space Telescope program has a history of underestimating resources for manufacturing and work already planned.

Do your new resources estimates include additional estimates for what I will refer to as the mainline manufacturing and fabrication effort?

ANSWER A-16:

The preliminary cost estimate which I gave does include revised estimates to complete all remaining manufacturing and fabrication effort in the development program. We expect to complete our detailed analysis of the revised cost and schedules by late summer or early fall of this year.

QUESTION A-17:

NASA is quadrupling the systems engineering effort. Is this perhaps an overreaction?

ANSWER A-17:

The systems engineering increases are predicted on our best assessment of the job to be performed. As the Space Telescope development progresses, the level of system engineering will be reassessed for appropriateness to the task. It should be noted that the increase in system engineering is significantly less than "quadruple."

QUESTION A-18:

a. Will the current design for the Fine Guidance Sensor meet all performance requirements?

b. If NASA is faced with launching in June 1986 with a Fine Guidance Sensor with some degraded performance of further delaying the launch for developing a new design, what would be your decision?

ANSWER A-18:

a. The Fine Guidance Sensor hardware and associated software, as currently designed, is expected to meet all performance requirements. Initial testing of the first unit in the past month has yielded positive results which strengthen this conclusion.

b. I believe the Fine Guidance Sensor will be ready for launch in the last half of 1986 and will meet all performance requirements. If there were some degraded performance, a decision to delay the launch would strictly depend on the degree of such degradation. Of course, such a decision would be closely coordinated with the appropriate Space Telescope scientists.

QUESTION A-19:

Will all Space Telescope Computer and Data Management Systems have the capability to be reprogrammed on-orbit?

ANSWER A-19:

Both the spacecraft computer, the DF224 built by North American-Rockwell, and the scientific instruments control and data handling computer built by IBM are reprogrammable on-orbit. The Data Management System is controlled by the spacecraft computer.

QUESTION A-20:

a. Is it desirable to be able to reprogram the Fine Guidance Sensors on-orbit?

b. Will this capability be available?

ANSWER A-20:

a. It is desirable to be able to reprogram the Fine Guidance Sensor computer on-orbit, principally to accommodate unanticipated or untested on-orbit effects, or any other unknowns which cannot be simulated accurately in the terrestrial environment.

b. A decision was made early in the program to produce a Fine Guidance Sensor which was not completely reprogrammable. The reasons for this decision were that the firmware approach would use less power, be less susceptible to influences of on-orbit radiation, and would reduce operational complexity. However, adequate flexibility for changes has been provided by permitting on-orbit change-out of the constants and key variable in the algorithms in the computer.

QUESTION A-21:

a. What is your new total cost estimate for the development program?

b. Could you provide a breakdown of how these additional funds will be used?

ANSWER A-21:

a. Our preliminary estimate for total Space Telescope development is in the $1.1 to $1.2 billion range. However, until we have completed a detailed analysis of all levels of the rebaseline activities, we will not have a firmer estimate. We expect to have this analysis completed by late summer or early fall of this year.

Mr. Volkmer. Thank you very much.

I have just a few questions right now and then I will submit some others in writing. We will hold the record open for your answers.

You mentioned that you learned some lessons from the space telescope development experience. Could you give us just a brief summary of those lessons?

Mr. Beggs. The most important lesson that we have learned from it is a lesson we probably have to learn over and over again, and that is that the management structure that we set up for these programs should be both adequately designed and adequately staffed to stay on top of the program completely during the course of the research and development phase of the program.

I do not think we devoted sufficient attention to the need for both systems engineering and systems management, more importantly probably the systems management aspect of it. We took on a difficult management challenge by reason of the way we contracted for the job. We have two associate contractors and then we contracted separately through Goddard for the instruments. That is, indeed, a difficult structure to maintain.

Mr. Volkmer. How did that come about?

Mr. Beggs. Mr. Chairman——

Mr. Volkmer. That is a little unusual.

Mr. Beggs. It is unusual, and I am afraid I cannot discuss it in open session, but I would be happy to discuss it with you in a closed meeting.

Mr. Volkmer. All right.

Mr. Beggs. In any event, it imposed on NASA the requirement to do the systems management job, as well as a special responsibility to both monitor and to exercise the management role. I am afraid that we did not do that in an adequate fashion, both from the point of view of staffing and from the point of view of a management organization. We waited too long in coming down hard when we knew problems were developing in our contractor's organization. We probably should have moved sooner on that. It was late last year before we fully understood the magnitude of the problem that we had, even though a couple of years earlier we had, had a management review which had uncovered some similar kinds of problems. The effective use of the two associate contractors was not completely carried out. We had entrusted to the Lockheed Co. a responsibility for systems engineering. They were not effectively used. We have, of course, sought to correct that, and I believe have corrected it now.

Of course, the fact that we had two different NASA centers involved resulted in some problems, the most important of which I think is communication. We clearly had a problem of communicating in the program.

Mr. Volkmer. That was within NASA?

Mr. Beggs. Within NASA and between NASA and its contractors as well as between the two contractors, all have had communication problems. I think that highlights the main issues, Mr. Chairman.

Mr. Volkmer. Was there anything built into the management system that formed barriers for communication?

Mr. BEGGS. No, not specifically. I think that the very existence of the structure, which is complex, and the fact that our program office, primarily at Marshall, was not staffed adequately had a major effect.

Mr. VOLKMER. Deficient in numbers?

Mr. BEGGS. Yes, sir.

Mr. VOLKMER. Were we also deficient in numbers at headquarters?

Mr. BEGGS. Possibly, although I do not think that was a serious problem. I think the lack of a specific dedicated office had some effect, and that is, of course, one of the things we have corrected by establishing a division within the Space Science and Applications Associate Administrator's office to manage it, which has corrected that problem.

We had relied on a group within an existing division, but it was not highlighted at the top level. I think that had a definite effect on communication.

Mr. VOLKMER. How many people do we actually have at headquarters involved in the space telescope program?

Mr. BEGGS. I will ask Sam Keller, as he is more familiar with the history of this. In the last year—perhaps a dozen. At one point or another, three or four people were directly involved and indirectly probably a dozen in monitoring the program.

Mr. VOLKMER. Was there any prohibition as to the integration of the system engineering contractor directly interacting with principal investigators and instrument contractors?

Mr. BEGGS. No, no prohibition. I think, again, the structure made that a little difficult.

One of those instruments, of course, is being built abroad. The solar panels are also being built in Europe and being supplied to us by ESA. I do not think that has caused a serious problem. I think the instruments are generally in pretty good shape at this time.

I do not believe that Lockheed has been inhibited in the design of the support systems module as a consequence of that. Their work has progressed reasonably well insofar as that particular integration task is concerned. There do, of course, remain some unknowns in the future as we integrate this entire instrument totally together.

Mr. VOLKMER. Personally, I want to commend you for what you have done on what has been brought to your attention and being able to bring about the midcourse corrections, in the management especially.

That is all the questions I have.

Does the gentleman from Virginia have any questions?

Mr. BATEMAN. Just one, Mr. Chairman, I believe.

Mr. Beggs, you have mentioned in your statement that the primary mirror has now been mounted in the ring.

Mr. BEGGS. Yes.

Mr. BATEMAN. I think that was the terminology. "Without any distortion." How do you test to determine whether or not that is the case or how do you know that?

Mr. BEGGS. We have a capability to test this mirror optically throughout the very broad spectrum across which it will operate. We have run that test, and in the ring, it meets the specification.

Therefore, we can say without fear of being wrong that it is in the ring and it is without distortion. When we mount it again in the optical telescope assembly, and then that, too, has to be mounted in the support systems module at Lockheed, we will have to check again to insure that we have not induced any stresses in the mirror. We have the test equipment and the capability to do that.

I am reasonably confident that the mirror and the mirror assembly, both primary and secondary, are going to be fine and are going to meet the specs. In fact, I believe they will exceed the specifications. We do have the problem of cleaning it, but we think we have the technique for doing that.

As was mentioned earlier by the Perkin-Elmer folks, we have decided to go back to the original requirement to vacuum bakeout the various pieces and parts that surround the mirror so as to prevent any potential contamination that could happen after it was launched into orbit as a complete assembly. I think we are taking sufficient precautions now to insure that the mirror will be not only free from contamination when launched, but will remain free from contamination during the several years that we will be operating the telescope before we bring it back to Earth for refurbishment.

Mr. BATEMAN. As frequently is the case, I am almost awestruck that you can say with certainty that this will happen when you are dealing with a device that is going to be looking millions of miles into space, that you can examine it in a cleanroom——

Mr. BEGGS. This is going to be a splendid instrument. The astronomers who are now working with us, literally from all over the world, are quite happy with what we have done to date. They have reviewed it. We just had a group of the scientists take another look at it.

The one problem that remains is to insure that we have a fine guidance system properly designed so that it will do the job that it is intended to do. It is, indeed, a very, very challenging job. We are going to be tracking down to seven one-thousandths of an arc second. Someone described it as a dime as viewed from Boston to Washington. It is a very, very fine job that we are attempting to do, and we will not know the answer to that until the first engineering model is delivered this summer and tested.

Mr. VOLKMER. In that regard, if the gentleman will yield a minute——

Mr. BATEMAN. Sure.

Mr. VOLKMER. Let's say that we are faced with a position that the fine guidance sensor does not perform to the extent that would be required in order to do what we want to do. We would be faced then, would we not, with developing a new design, delaying the launch, or going ahead with——

Mr. BEGGS. I do not believe so, Mr. Chairman. We have posed that question to our astronomer friends. The question goes something like this: We feel reasonably confident—and we have reviewed this very carefully technically—that we can achieve fine guidance close to that 0.007 arc second requirement. If we have a problem, it will be a problem that we do not quite make that specification, and the impact of that on the observations will be that we will not be able to track very accurately very distant objects or very, very faint objects, which of course is one of our objectives. The astronomers say, faced with that, they would still opt to go with the slightly less accurate system because it would give them 90 or 95 percent of what we are looking for, and then when we go to refurbish the instrument, we can develop a better system and install it at that time. That is my view. Both Dr. Mark and myself have reviewed the progress that we have made to date on that.

What you are using is two guide stars of 14.5 visual magnitude, and that is an exceedingly dim, faint star. Those prisms that the Perkin-Elmer people were talking about have to have very, very sharp edges, because you are actually splitting the light beam from that very dim, faint star. We have reviewed it very carefully, as have a number of others in the NASA organization. It is our view that it has a reasonably good chance of achieving that performance, but if we miss, we will miss as a matter of degree, not in totality.

Now, we are looking at a possible alternative system, must with an abundance of caution. We also have the Applied Physics Laboratory at Johns Hopkins examining another system. As I say, if we do not quite make the full accuracy, we would proceed with a parallel system, with the objective of installing it later, after we had had the telescope in operation.

Mr. VOLKMER. Does the gentleman from Virginia have any additional questions.

Mr. BATEMAN. One last question.

Mr. Beggs, in a contract of this kind, while there may have been peculiarities in this one, there are many common points, I am sure, with many sophisticated R&D contracts, in that there are technical changes, unforeseen delays, optimism as to how easily technological problems can be resolved, and this calls for extensions of time, allowances of larger funds.

As a matter of policy—or is it a matter of policy that when this becomes necessary you do look at the baseline inflation projections the original contract was based upon to see if it has not been as egregious as was feared, adjustments running to this side of the table can be made?

Mr. BEGGS. We tried to anticipate technical problems in several ways. The most important, of course, is that we do put into our estimates a reserve for contingencies. The budget cycle does impose some constraints on the degree that we can do that when we run into problems because, generally speaking, we are setting budgets 2 years ahead of the time that we spend the money.

In every case that I have reviewed in the history of this program we have taken the best estimates that we have been able to get from our contractors. We have added a program contingency reserve to those estimates, and we have put that in the budget. This was not a case of trying to hedge or slice or pare the estimates that our contractors made. We took what they considered their honest estimates and used those.

Unfortunately, as we started to develop trouble, it kind of cascaded on us. The slip in schedules at Perkin-Elmer meant that we had a slip in schedule at Lockheed. The consequence of that was that the costs on both contractors went up as a function of time. Therefore, our estimates were continually running behind what the actual situation was turning out to be. Our reserves were not adequate, in spite of the fact that as recently as September of last year, we thought our reserves would be adequate to cover this. The current funding problems only came to light in the December-January time period. As I think Mr. Fordyce said, the dimensions of their problem only came into focus in the Christmas holidays. It got to me right after the new year. We immediately went to work to understand the dimensions of the problem and then we notified the committees as well as the OMB that we had a problem.

We are still in the throes of getting our hands around that. I said $1.1 billion to $1.2 billion is our best estimate. I really cannot narrow it any more than that right now. It is a function of time, and we will need to nail down the end date. Once we do that, we will be able to give you a fairly accurate number.

Mr. Bateman. Mr. Chairman, that is all the questions I have. You mentioned the record might remain open.

Mr. Volkmer. If you have additional questions, you may submit them to any of the witnesses in writing.

I would just like to say thank you, Mr. Beggs, for being here.

When you do come up with the additional costs, if it is possible, I would like to see a breakdown as to what costs can be attributed to keeping this marching army of people in place for the additional time that we are going to have.

Mr. Beggs. Yes, sir.

Mr. Volkmer. I would like to have those figures, also.

Mr. Beggs. We will do that.

[The information follows:]

At this time, we have not yet completed our rebaselining activities. We will provide a breakdown of the requested costs to the subcommittee as soon as they are available.

Mr. Volkmer. Thank you very much.

Mr. Beggs. Thank you, sir.

Mr. Volkmer. The subcommittee will stand adjourned.

[Whereupon, at 5:04 p.m., the subcommittee adjourned.]

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